3. Chapter Three, Site, Facilities and Operations Description

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3.1. Characterization of the Site

The site geography is such that BNL is located near the center of Suffolk County, Long Island, about 60 miles east of New York City. Most of the principal facilities are located near the center of the BNL's 5,265-acre site. The developed area is approximately 1,650 acres, consisting of about 500 acres originally developed by the Army, as part of Camp Upton. The developed area is still used for offices and other operational buildings; 200 acres occupied by large, specialized research facilities; 550 acres occupied by outlying facilities, such as the Sewage Treatment Plant, research agricultural fields, housing, and fire breaks; and 400 acres of roads, parking lots, and connecting areas. The balance of the site, approximately 3,600 acres, is largely wooded and it represents native pine barren ecology. See Figure 3.1.

Figure 3.1 Site Overview

The probable occurrence of an earthquake sufficiently intense to damage buildings and structures in the BNL area was investigated as part of the planning for construction of the Relativistic Heavy Ion Collider. It is the consensus of seismologists that no significant earthquakes are to be expected in the near future. No earthquake has yet been recorded in the BNL area with intensity in excess of modified Mercalli III, equivalent to 1- to 8-cm/s^2 acceleration.[1] However, since Long Island lies in a Zone 1 seismic probability area, it has been assumed that an earthquake of Intensity VII could occur, 5.6 on the Richter scale, which is negligible damage of good design and construction.[2] Liquefaction potential of soils at BNL for such an event is negligible given existing soil density and saturation parameters. Thus, structural stability should remain through an event of this magnitude. No active earthquake-producing faults are known in the Long Island area.[3]

The C-A Department reviewed DOE's seismic hazard order and standard (DOE Order 1022-94 and DOE Standard 1023-93) and the Uniform Building Codes for the region and developed guidelines for review of seismic hazards. These guidelines are used for construction of facilities and experiments.

The meteorology is such that prevailing ground level winds at BNL are from the southwest during the summer, from the northwest during the winter, and about equal from these two directions during the spring and fall. Recent meteorological data show the total annual precipitation to be 50 inches. The monthly mean temperature is about 54 °F, ranging from a monthly mean low temperature of 32 °F in January to a monthly mean high temperature of 76 °F

[1] U.S. Department of Energy, Environmental Assessment, Relativistic Heavy Ion Collider at Brookhaven National Laboratory, Upton, New York, DOE/EA# 0508, January 1992.
[2] Pepper, S. "Seismic Event Prediction," Memorandum to T. Sperry, August 6, 1992.
[3] U.S. Department of Energy, Final Environmental Impact Statement, Proton-Proton Storage Accelerator Facility (ISABELLE), DOE/EIS# 0003, August 1978.

in July. The average annual mean temperature shows a continuing trend of increasing annual temperatures. In general, annual mean temperature at BNL has increased 1.9 °F over the last 50 years, compared to a worldwide average surface-temperature increase of 0.55 °F.

The hydrology is such that the BNL site is underlain by approximately 1,300 feet of unconsolidated Pleistocene and Cretaceous sediments overlying Precambrian bedrock. The unconsolidated sediments, subdivided from youngest to oldest, are as follows:

- Upper Pleistocene deposits or Upper Glacial aquifer
- Gardiners Clay or confining unit
- Magothy Formation or Magothy aquifer
- Raritan Formation or Raritan Clay confining unit and Lloyd aquifer

The Upper Glacial aquifer is widely used on Long Island for both private and public water supply. Drinking water and process water supplies at BNL are obtained exclusively from the Upper Glacial aquifer. The Laboratory currently operates six potable water supply wells that can be pumped at rates of 1,200 gpm, and five process supply wells that can be pumped at rates between 50 and 1,200 gpm. During maximum water usage at BNL, up to 6 MGD are pumped from the Upper Glacial aquifer. Most of this water is returned to the aquifer by way of recharge basins or discharge of Sewage Treatment Plant (STP) effluent to the Peconic River. Groundwater in the Upper Glacial aquifer beneath BNL generally exists under unconfined conditions. However, in the areas along the Peconic River where low permeability near surface silt and clay deposits exist, semi-confined conditions may occur. Depth to groundwater varies from several feet below land surface, such as within the lowlands near the Peconic River, to as much as 75 feet in the higher elevation areas located in the central and western portions of the site. The Long Island aquifer system has been designated by the U.S. EPA as a Sole Source Aquifer System, pursuant to Section 1424(e) of the Safe Drinking Water Act. Groundwater in the sole source aquifers underlying the BNL site is classified as "Class GA Fresh Groundwater" by the State of New York (6NYCRR Parts 700-705). The best usage of Class GA groundwater is as a source of potable water supply. As such, federal drinking water standards, NYS Drinking Water Standards and NYS Ambient Water Quality Standards for Class GA groundwater are used as groundwater protection and remediation goals.

For drinking water supplies, federal maximum contaminant levels (MCLs) set forth in 40 CFR 141 and 40 CFR 143 apply. The Laboratory maintains six wells and two water-storage tanks for supplying potable water to Laboratory community. In NYS, the Safe Drinking Water Act requirements pertaining to the distribution and monitoring of public water supplies are promulgated under Part 5 of the NYS Sanitary Code, which is enforced by the SCDHS as an agent for the NYS Department of Health. These regulations are applicable to any water supply that has at least five service connections or regularly serves at least 25 individuals. The Laboratory supplies water to a population of approximately 3,500 employees and visitors and must comply with these regulations. In addition to MCLs, DOE Order 5400.5, Radiation Protection of the Public and Environment, establishes Derived Concentration Guides for radionuclides not covered by existing federal or state regulations.

The BNL groundwater-surveillance program uses monitoring wells, which are not utilized for drinking water supply, that are designed to monitor C-A Department facilities where there is a potential for environmental impact, or in areas where past activities have already degraded groundwater quality. BNL evaluates the potential impact of radiological and nonradiological levels of contamination by comparing analytical results to NYS and DOE reference levels.

The predominant groundwater flow direction is to the south-southeast. The closest BNL potable water supply to C-A Department facilities is supply-well-10 located approximately 2,100 feet to the east. Results from supply well capture zone modeling indicates that under sustained pumping conditions, approximately 8 to 10 years would be required for groundwater to travel from the closest C-A Department facility to supply-well-10. Well 10 has been shutdown since 1999.

The demography is such that about a third of the 1.37 million people that reside in Suffolk County live in Brookhaven Township where the Laboratory is situated. Approximately eight thousand people live within 0.3 miles of the Laboratory's boundaries.

Funding from the U.S. Department of Energy drives the demography of the BNL site. Brookhaven National Laboratory is a multi-program scientific center that develops and operates large-scale, state-of-the-art research facilities that are beyond the capability of any single university. In carrying out DOE's mission at the Laboratory, BNL's staff conducts its own basic and applied research at the frontiers of science through long-term programs in physics, chemistry, biology, medicine, energy and environmental sciences, and nonproliferation and national security. In addition, Brookhaven's 3,000 scientists, engineers and support staff collaborate and/or meet the needs of the more than 4,000 visiting researchers who come to the Laboratory each year from across the country and around the world.

Today, the Laboratory is home to five Nobel Prize-winning discoveries in physics. The first Nobel Prize for research developed at BNL was awarded in 1957, for a theory on parity conservation. The physics prizes in 1976, 1980 and 1988 were awarded for discoveries made using Brookhaven's Alternating Gradient Synchrotron (AGS), which is part of C-A Department. A chemist at Brookhaven National Laboratory, won the 2002 Nobel Prize in Physics for detecting solar neutrinos, ghostlike particles produced in the nuclear reactions that power the sun.

The AGS is one of the world's premiere particle accelerators and together with the AGS-Booster are the only heavy-ion accelerators for radiation-biology research in the U.S. In addition, the AGS serves as a pre-accelerator for the Laboratory's Relativistic Heavy Ion Collider, which is the world's newest and biggest particle accelerator for nuclear physics research.

Since 1998, Brookhaven Science Associates (BSA), a nonprofit, limited-liability company established in 1997 by Battelle and the Research Foundation of the State University of New York (SUNY) for SUNY at Stony Brook, has operated BNL under contract with the U.S. Department of Energy. BSA's goal is to encourage internationally significant and nationally important science research to be done at Brookhaven, while ensuring the quality of the Long Island environment, the safety of the surrounding community, and the health of the Laboratory's staff and visitors.

Founded in 1977 as the 12th cabinet-level federal department, the U.S. Department of Energy oversees much of the energy-related scientific research in the U.S., through its support of BNL and the eight other national laboratories. The U.S. Department of Energy not only provides the majority of Brookhaven's research dollars and direction, but also it is the government agency responsible for the Laboratory's operations and environmental stewardship.

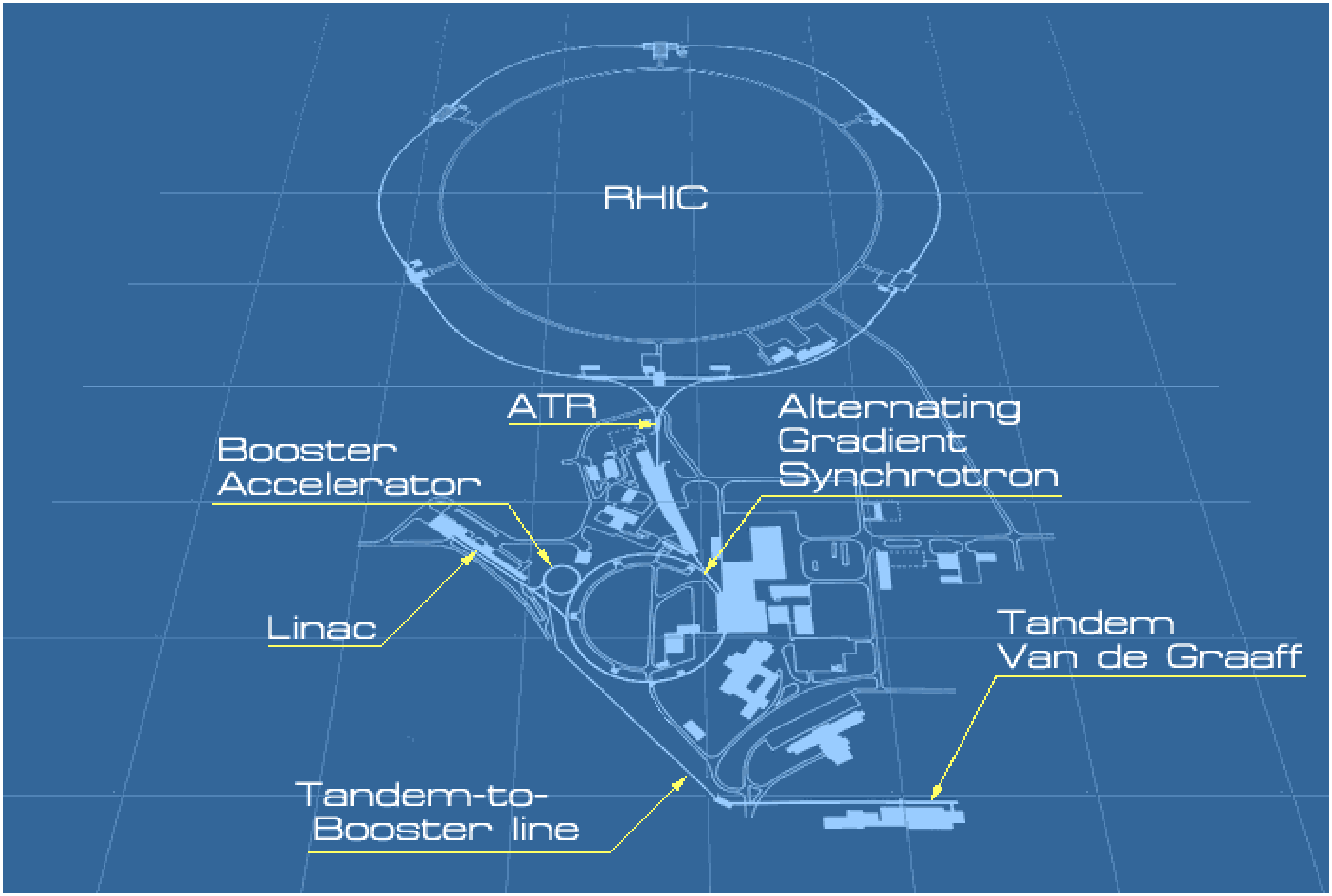
3.1.1.Characterization of the Accelerators and Experimental Facilities

The Collider-Accelerator Department is responsible for over 120 buildings and additional structures such as cooling-water towers and shield-block yards. These facilities are further described in Facility Use Agreements (FUAs). Links to FUAs, facility pictures and the list of Building Managers are located at the C-A Department's ESHQ web site.

Figure 3.1.1.a shows a schematic of the Collide-Accelerator complex. There are seven accelerators in operation. They include:

- two collider rings, which are known as the Relativistic Heavy Ion Collider (RHIC)
- main injector, which is known as the Alternating Gradient Synchrotron (AGS)
- Booster accelerator, which supports the NASA Space Radiation Laboratory (NSRL), AGS and RHIC programs
- pre-injectors known as the Linac and the two Tandem Van De Graaff (TVDG) accelerators

Figure 3.1.1.a Schematic of Collider-Accelerator Complex

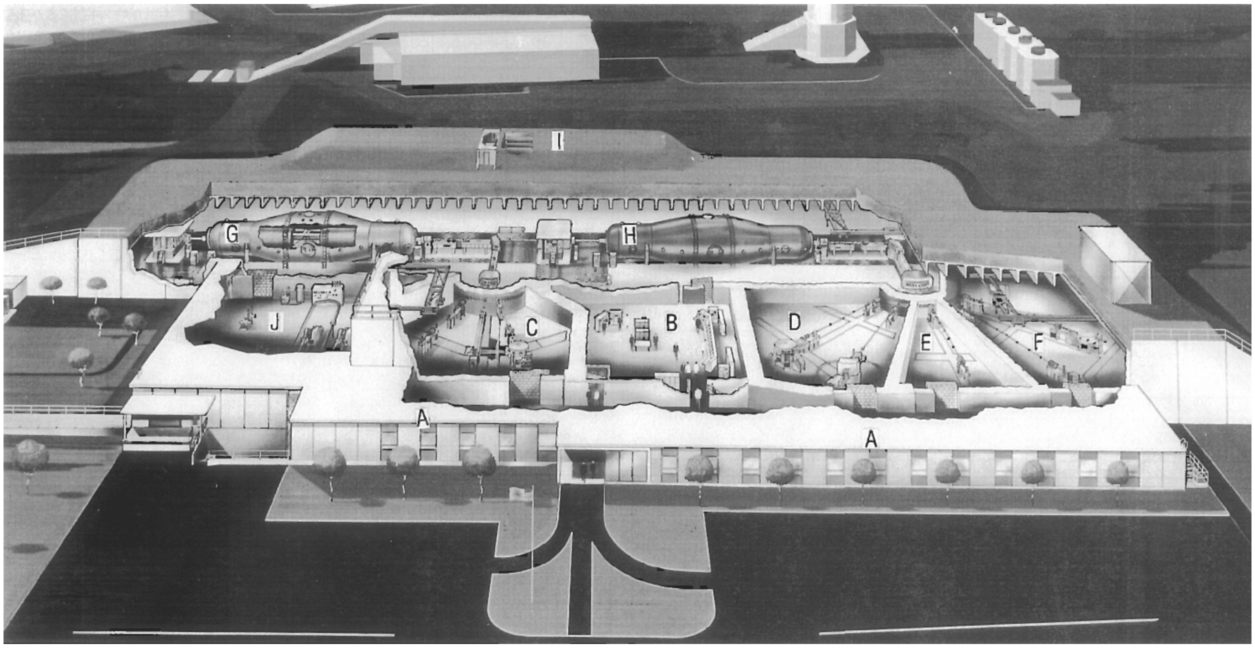


Completed in 1970, the TVDG pre-injector facility was for many years the world's largest electrostatic accelerator facility. It can provide researchers with beams of more than 40 different types of ions that have been stripped of their electrons. Ions ranging from hydrogen to uranium are available. The facility consists of two 15 MeV accelerators, each about 75-feet long, aligned end-to-end. See Figure 3.1.1.b.

Figure 3.1.1.b Tandem Van De Graaff Accelerators

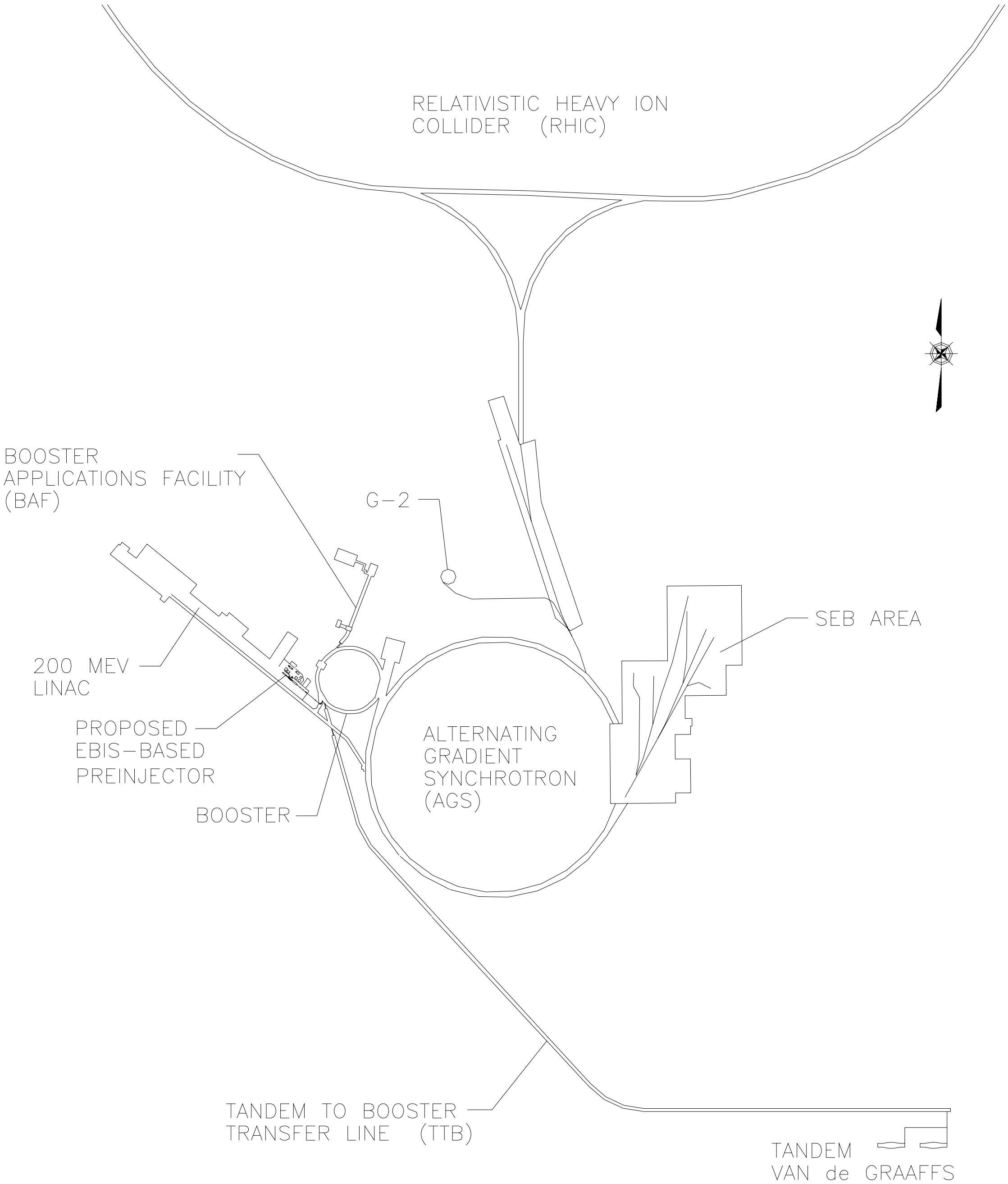
The Radiation Effects Testing and Calibration facility at TVDG is available for the study of space radiation effects, in particular, Single Event Upset (SEU) Testing and Spacecraft Instrument Calibration. The ion energies may range from 29 MeV protons to 385 MeV uranium ions. Ion irradiation and implantation are also available for other ion-beam related applications. Heavy-ion research for nuclear physics was started at the TVDG in 1970. Since 1986, at least one of the accelerators has served as the heavy ion injector for the Booster or AGS. In 1999, heavy ions from the TVDG were transported through the Booster and AGS and into the Relativistic Heavy Ion Collider. Since 2003, TVDG has served as an injector to Booster for supplying heavy ion beams that are extracted from the Booster into the NASA Space Radiation Laboratory (NSRL). The NSRL radiobiology research program is related to the investigation of space radiation on humans and is particularly important for the planning of future long-term deep space flights. The layout of the TVDG facilities is shown in Figure 3.1.1.c.

Figure 3.1.1.c TVDG Facility Layout: Offices/Labs (A), Control Room (B), Target Rooms (C, D, E, F), Accelerators (G, H), Insulating Gas Storage (I), Mechanical Equipment Room (J)



To study heavy-ion collisions at high energies, a 2700-foot tunnel and beam transport system called the Tandem to Booster (TtB) Line were completed in 1991, allowing the delivery of heavy ions from TVDG to the Booster for further acceleration. This line was an extension of the former Heavy Ion Transfer Line (HITL) that allowed for direct injection of heavy ions from TVDG into AGS. The HITL transport system no longer exists; however, the spur tunnel leading directly to AGS is still present. The TtB tunnel was constructed to extend the transport of heavy ions from the Tandem to the Booster because the excellent vacuum levels in the Booster allow partially stripped ions heavier than sulfur to be accelerated to intermediate energies and then fully stripped before AGS injection. This feature ultimately allowed heavy ions of all species to be injected into RHIC for colliding beam physics. The TtB (HTB plus HITL) tunnels are shown in Figure 3.1.1.d.

Figure 3.1.1.d Sketch of Transfer Line for Heavy Ions from TVDG to Booster

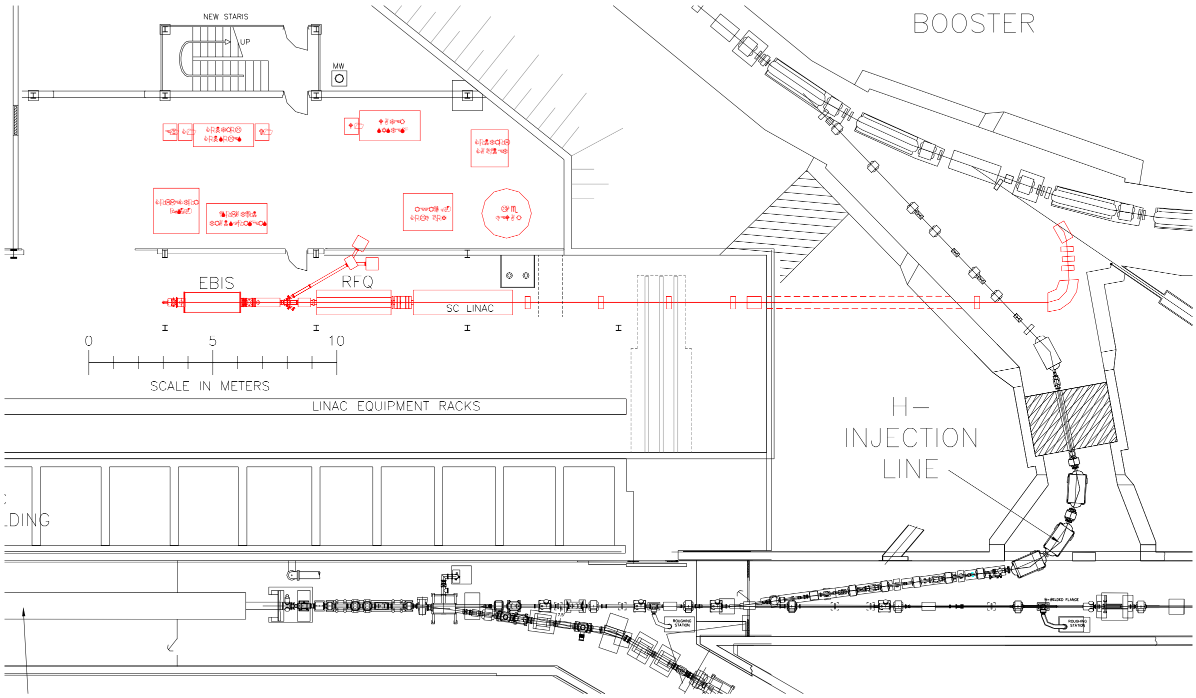


In the near future, a second heavy-ion pre-injector, the Electron Beam Ion Source (EBIS), will be housed in the 200-MeV Linac building with a short tunnel section connecting to the

Booster. The EBIS is small and compact when compared to the TVDG pre-injector facility and the TtB line, and it is intended to replace these facilities.

This new heavy ion pre-injector for RHIC is based on an intermediate charge-state heavy-ion source, a Radio Frequency Quadrupole (RFQ) accelerator and a short superconducting Linac. The highly successful development of an EBIS at BNL now makes it possible to replace the present TVDG with a reliable, low maintenance Linac-based pre-injector. Linac-based pre-injectors are presently used at most accelerator and collider facilities with the exception of RHIC, where the required gold beam intensities could only be met with a Tandem until the recent EBIS development. The high reliability and flexibility of the new Linac-based pre-injector will be an essential component for the long-term success of the RHIC facility. This new EBIS also has the potential for significant future intensity increases, and can produce heavy-ion beams of all species including uranium beams. It could also be used to produce in-house polarized ^{3}He beams. These capabilities will be critical to the future luminosity upgrades and electron-ion collisions in RHIC. The new RFQ and linac that are used to accelerate beams from the EBIS to energy sufficient for injection into the Booster are both very similar to existing devices already in operation at other facilities. Injection into the Booster will occur at the same location as the existing injection from the Tandem. A sketch of the facility is shown in Figure 3.1.1.e.

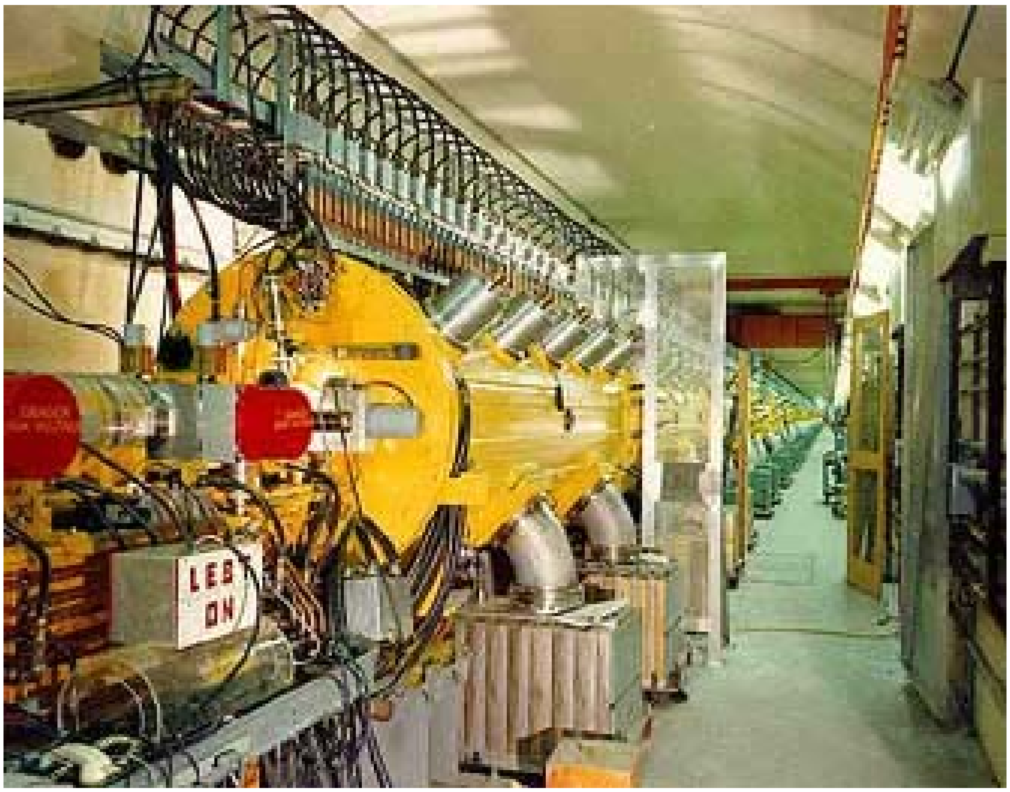
Figure 3.1.1.e Schematic Showing the Planned EBIS Pre-injector (in red) in the Lower Equipment Bay of the 200-MeV Linac



The 200-MeV Linac was designed and built in the late 1960's as a major upgrade to the AGS complex. Before the 200-MeV Linac, a 50-MeV Linac was used to inject protons into the AGS. The 200-MeV Linac's purpose is to provide accelerated high-intensity protons for use at AGS, polarized protons at RHIC, and high-intensity protons at a Medical Department facility known as the Brookhaven Linac Isotope Producer (BLIP). The basic components of the 200-MeV Linac include ion sources, a radiofrequency quadrupole pre-injector and nine accelerator radiofrequency cavities spanning the length of a 460-foot tunnel. The Linac is capable of producing up to a 35-milliampere proton beam at energies up to 200 MeV for injection into the Booster or for the activation of targets at the BLIP. The BLIP targets are used by the Medical

Department to produce radiopharmaceuticals for human studies. The Linac tunnel is shown in Figure 3.1.1.f.

Figure 3.1.1.f Linac Tunnel

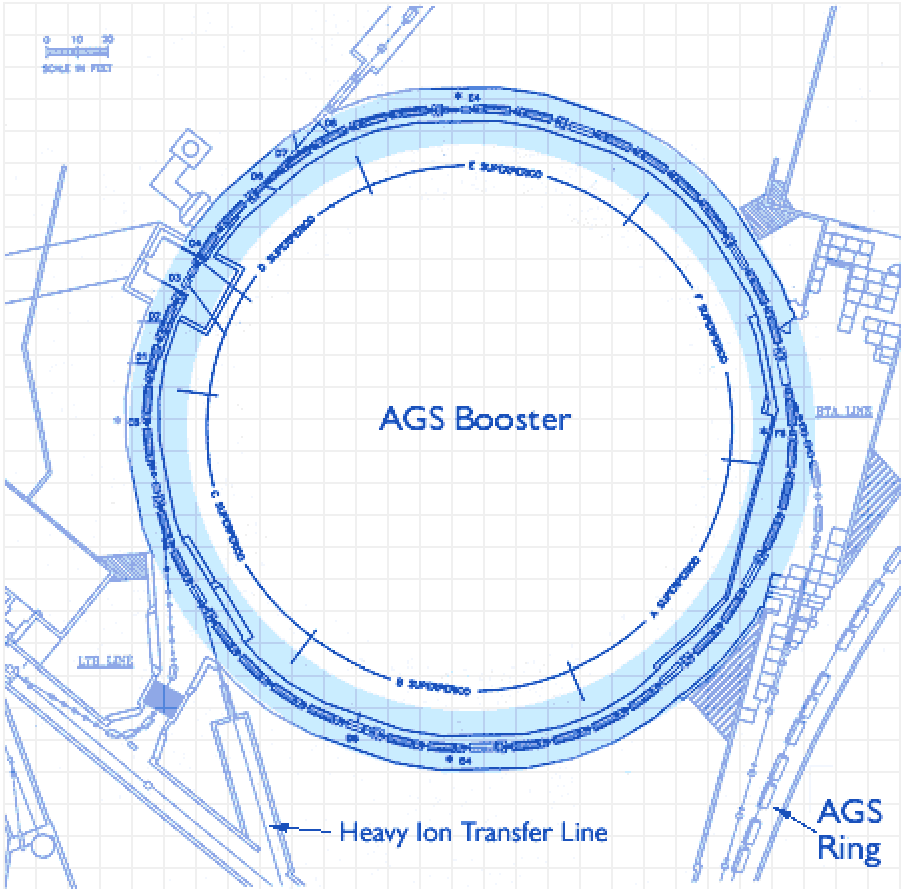


Construction of the Booster was begun in 1986 and completed in 1991. The Booster is a circular accelerator with a circumference of 600 feet, one fourth of the AGS, and is at the north corner of the AGS near the 200-MeV Linac. It is used to pre-accelerate particles entering the AGS ring, increasing the intensity of the particle beams generated by the AGS. A schematic of the Booster is shown in Figure 3.1.1.g. The schematic of the complex, Figure 3.1.1.a, illustrates how the Booster fits into the general arrangement. The Booster receives proton beams from the

Linac and heavy ion beams from the TVDG. The Booster injects higher energy beams through a fast extraction port and beam transport line into the AGS. The Booster increases the proton and polarized-proton flux in the AGS by a factor of four to six over that attainable by direct injection from Linac. Additionally, it allows higher mass ions to inject into the AGS, which is a key feature leading to the successful operation of RHIC. During routine operations, protons accelerate in the Booster at a flux of $6x10^{13}$ per second; that is, $1.5x10^{13}$ protons per pulse at 4 Hz, to energy of about 1.5 GeV. The pulse frequency can increase to 7.5 Hz, the proton energy can increase to about 2.1 GeV and the potential flux can be $1x10^{14}$ protons per second.

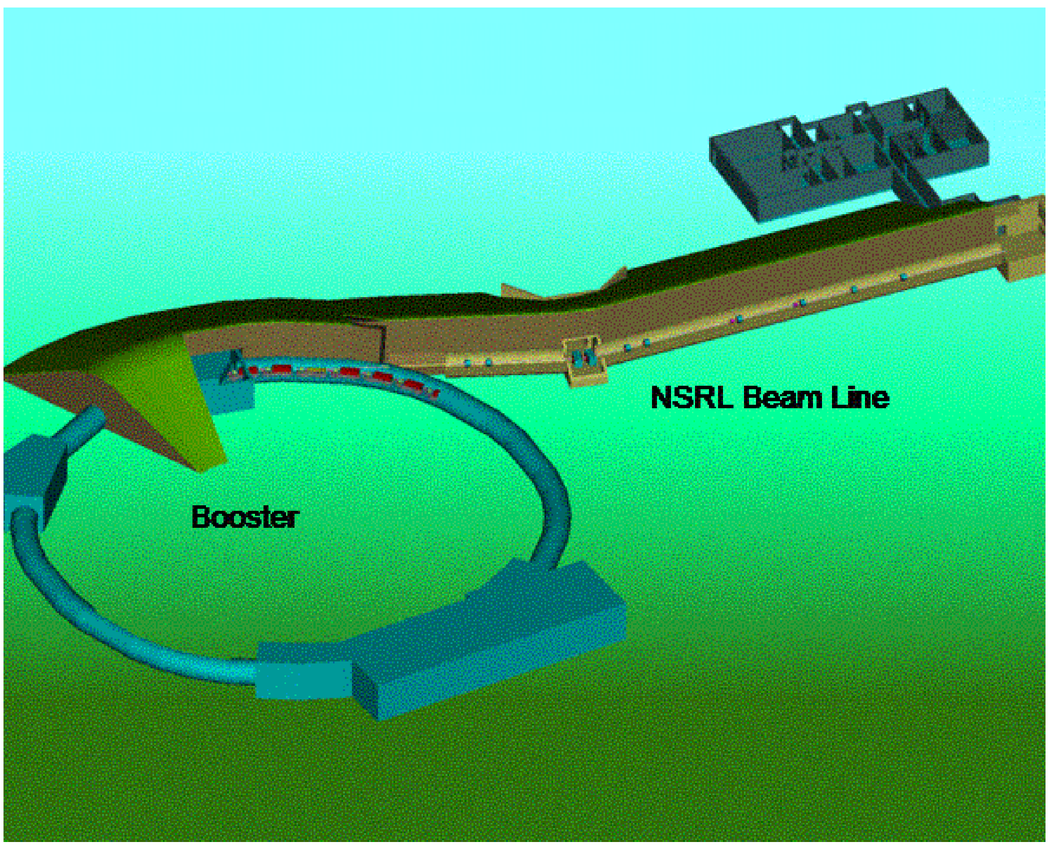
The Booster receives one pulse of heavy ions from the TVDG that it accelerates to energies between 0.3 and 1 GeV per nucleon with an acceleration cycle of about 1 second, before stripping the accelerated ions of most of the electrons and injection into the AGS. The flux and the energy of the beam depend on the mass and charge of the accelerated ion. The number of ions per second extends from $3x10^{11}$ for deuterons to $3x10^{9}$ for gold. In general, for heavy ions the total number of nucleons per second is about $6x10^{11}$ at a maximum energy of about 1 GeV per nucleon.

Figure 3.1.1.g Schematic of the Booster



The NASA Space Radiation Laboratory (NSRL) is an experimental facility designed to take advantage of heavy-ion beams from the Booster accelerator. This facility is used for radiation biology studies, which are of great importance to the future of manned space flight. Radiation fields encountered in space may cause adverse health effects in humans. These effects are of special concern for prolonged space missions beyond the earth's protective magnetic field. Before such missions can be undertaken, a much more detailed understanding of these effects is needed to plan for the effective protection of astronauts. The Brookhaven AGS Booster is an ideal accelerator for these studies due to the good overlap between the available ions and energies with those encountered in space. Heavy-ions originate in the TVDG and travel through TtB to Booster for acceleration to high energies. Energetic heavy-ion beams are then delivered to a shielded NSRL target room where various specimens are exposed. Figure 3.1.1.h shows the layout of the NSRL facility with respect to the Booster.

Figure 3.1.1.h Schematic of NSRL Line, Target Room and Experimental Support Building



Of particular concern are the radiation effects due to the heavy ion components of galactic cosmic rays. There is considerable uncertainty regarding the risks associated with the high dose rates that would be encountered in long-duration space flight. Many studies with cells, tissue and animals are required to obtain adequate estimates of radiation-associated risks to humans in space. Such studies are conducted under controlled conditions utilizing ion beams that originate form the Tandem Van de Graff accelerator. The AGS Booster accelerates the TVDG ions to energies that match those encountered in space. The resulting energetic heavy ion beams are then delivered to a shielded NSRL target room where various specimens will be exposed. See Figures 3.1.1.i through 3.1.1.k that show different views of the facility.

Figure 3.1.1.i NSRL Facility off the AGS Booster

Figure 3.1.1.j NSRL Facility Plan View

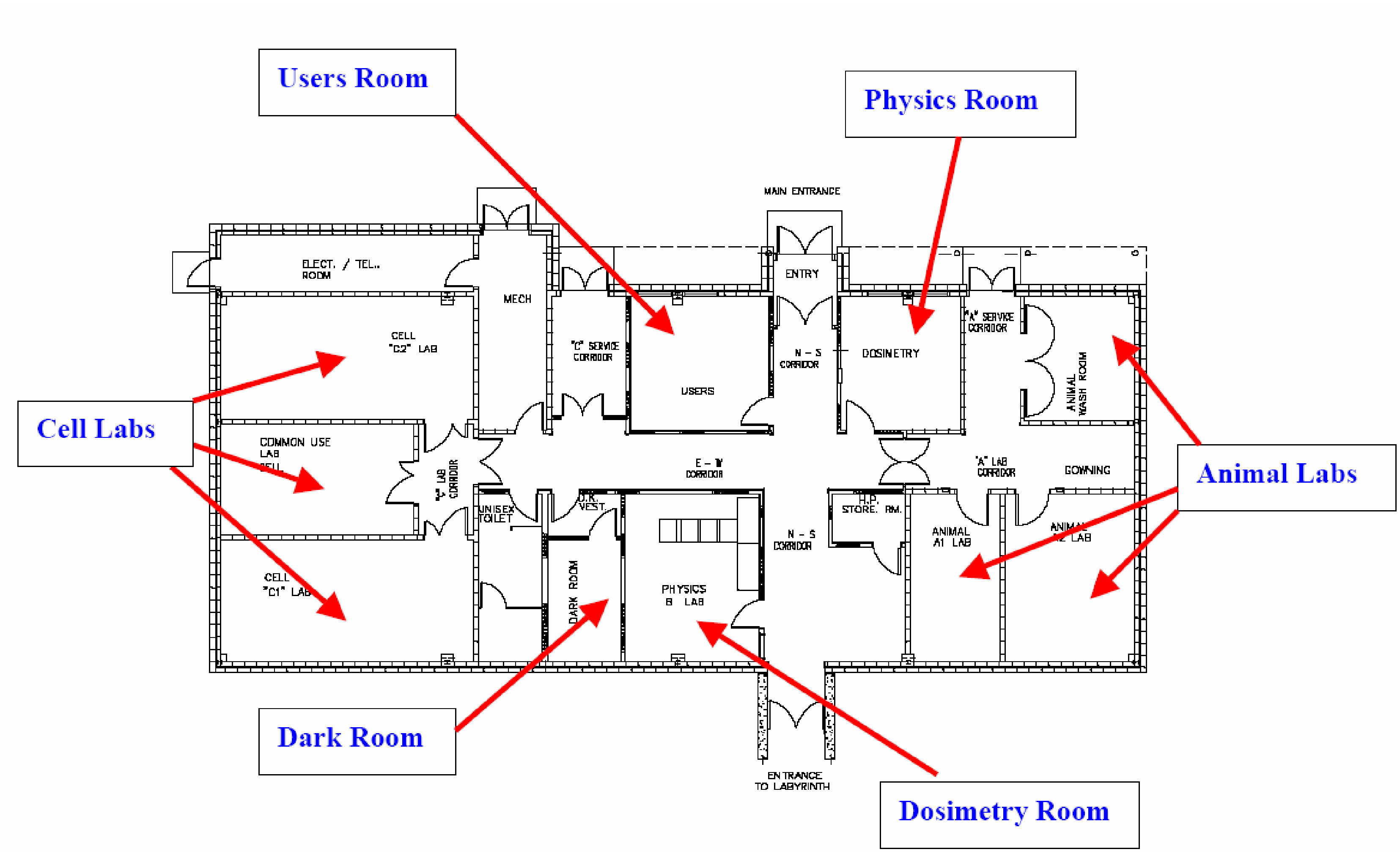
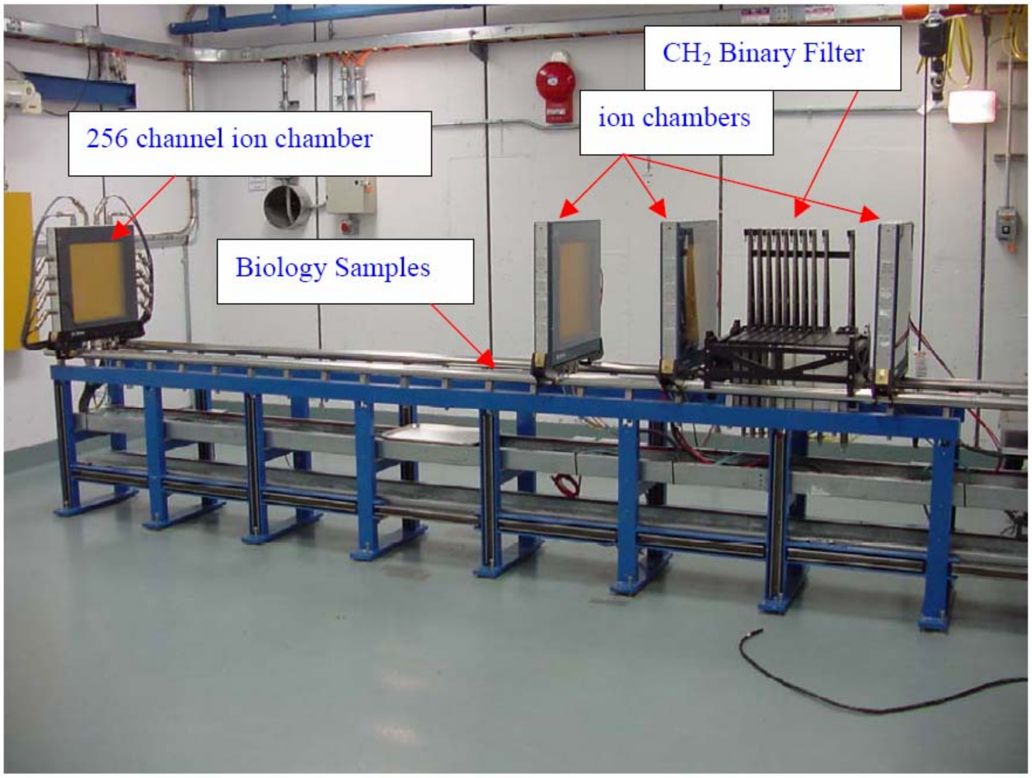


Figure 3.1.1.k NSRL Facility Target Room



Since 1960, the Alternating Gradient Synchrotron (AGS) has been one of the world's premiere particle accelerators, well known for the three Nobel Prizes won because of research performed with the particle beams. The AGS name is derived from the concept of alternating gradient focusing, in which the field gradients of the accelerator's 240 magnets are successively alternated inward and outward, permitting particles to be propelled and focused in both the horizontal and vertical plane at the same time. See Figure 3.1.1.l. The AGS is capable of accelerating $8x10^{13}$ protons (80 TP) with every pulse, and is available to accelerate heavy ions such as gold and iron. The AGS is used as an injector for the RHIC and as the final accelerator for high-intensity-proton fixed-target programs.

Figure 3.1.1.l AGS Magnet Enclosure

Figure 3.1.1.m shows the 5-acre experimental area, the g-2 experimental area and the AGS to RHIC line (AtR). More detail is shown in Figure 3.1.1.n. These areas take the output of the AGS and use it for experiments or for injection into RHIC. The Slow External Beam (SEB) exits the AGS via the F-10 extraction magnet. The SEB is focused by quadrupole magnets, and then it enters the switchyard. In the switchyard, electrostatic septa divide the beam into as many as four different paths, A-D. Each new beam is some fraction of the original intensity. Each of these beam lines are then confined and directed by arrays of quadrupole and dipole magnets to a production target and beam dump. The target, typically platinum metal with dimensions of a few inches, is the source of secondary particles of various species and a wide range of energies.

Secondary beam lines originate at these targets, gathering and admitting particles of the desired mass, charge and momentum using beam separators, and guiding the secondary beam, via magnets, to the experimental apparatus. This is usually a target where the interaction of interest takes place, surrounded by detectors, by means of which the interactions can be reconstructed. During operations, the radiation near the A through D beam lines or in the A through D target caves can be lethal. Each beam line is shielded with a combination of concrete blocks and steel. Occasionally some other materials may be used such as lead packing to seal interstices in the shielding. The total shielding inventory is 350,000 tons. The concrete shielding is generally loaded with ilmenite for a density of 3.5 g/cm^3, compared to normal concrete of 2.3 g/cm^3. Ilmenite is a naturally occurring iron titanium oxide. The steel is in the form of 10-ton buoy mooring blocks, steel armor plate up to 1.5 feet thick from scrapped naval vessels, and steel plate from other sources.

Figure 3.1.1.m AGS Experimental Areas and the AtR

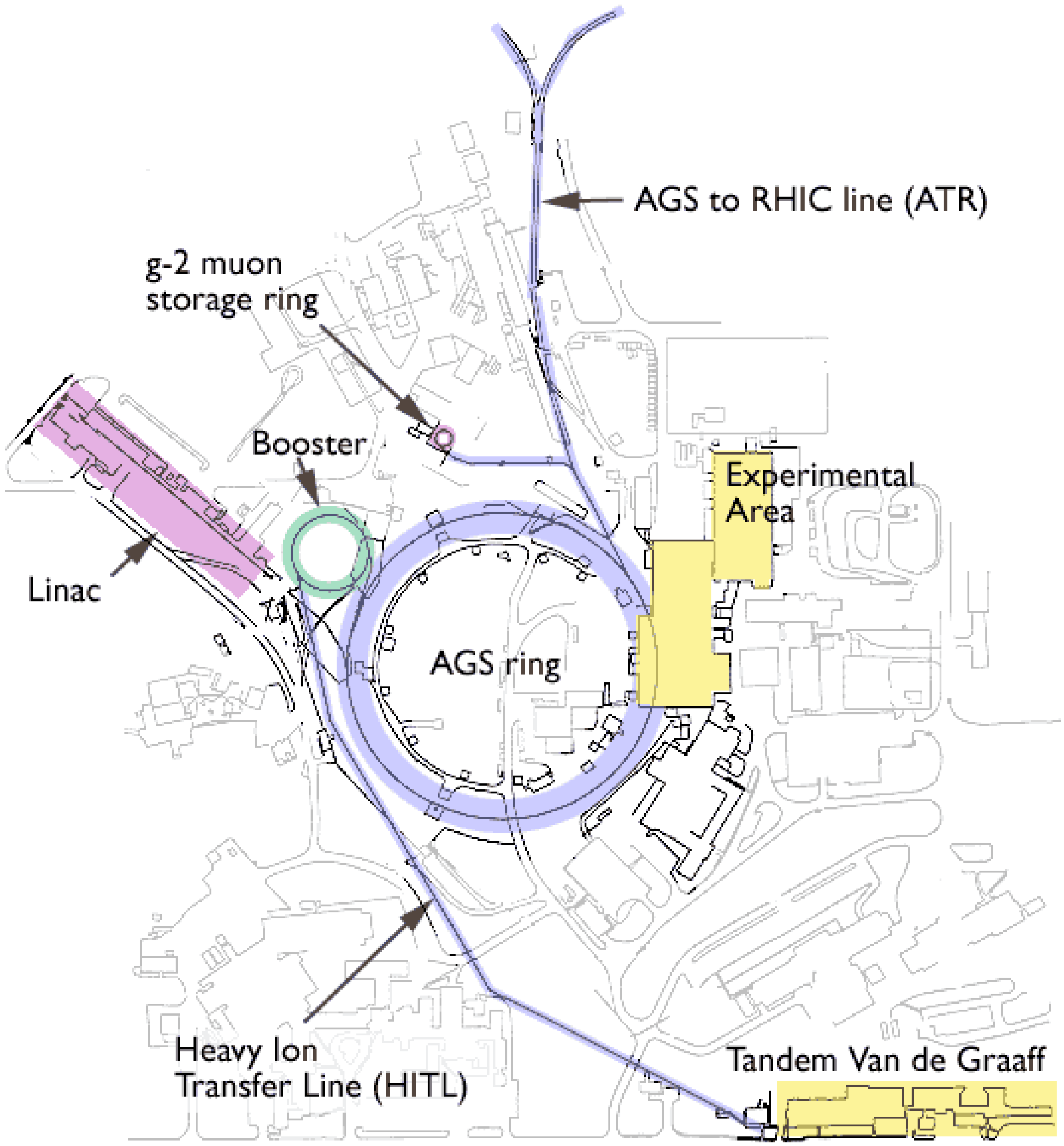
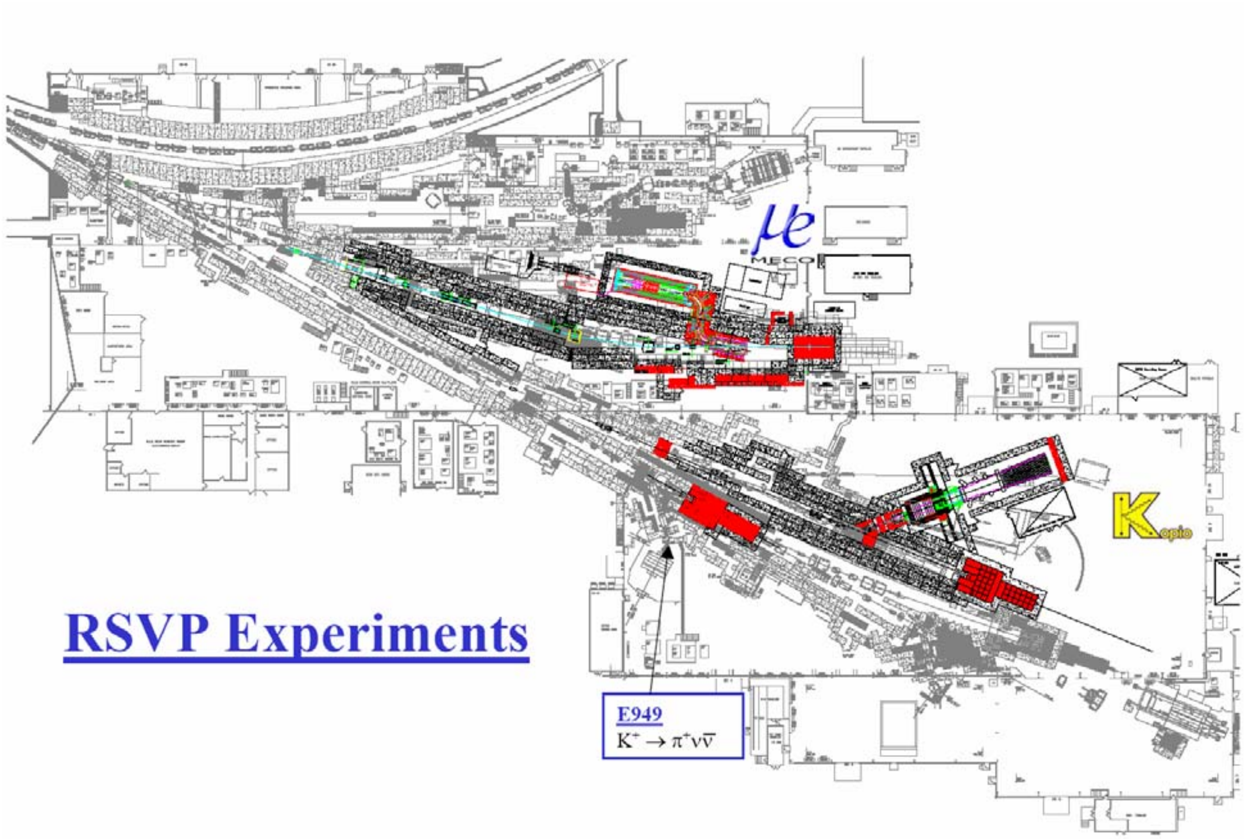


Figure 3.1.1.n Example of AGS Experimental Beam Lines



Experiments to be conducted in Building 912 include two experiments funded under the Rare Symmetry Violating Processes (RSVP) contract with the National Science Foundation. The RSVP program consists of the Muon to Electron Conversion (MECO) and the K Zero to Pi Zero (KOPIO) experiments. Together these experiments will be performed at the BNL Alternating Gradient Synchrotron (AGS) for 27 weeks per year.

The MECO and KOPIO experiments are examples of an approved class of experiments currently authorized by DOE for the AGS. Environmental, safety and health issues associated with this class of experiments were documented in the AGS Safety Analysis Report[4] and the AGS Environmental Assessment[5].

The scientific objective of the MECO experiment is to detect an example of the process of a muon converting to an electron in the field of a nucleus. The experiment is designed to detect a rate for this process as small as 2×10^{-17} times the rate for the process in which a muon is captured on a nucleus, changing the nuclear charge by one unit and emitting a neutrino. To date, no examples of a charged-lepton changing "flavor" have been observed, despite ever more sensitive searches being done since the 1940's. If the process is discovered, it will be evidence for fundamentally new physics outside the current understanding of elementary particles and their interactions, as described by the Standard Model. The expected sensitivity of the MECO experiment is approximately 10,000 times that of current experiments, and represents a tremendous discovery potential.

The proton beam used to produce the required muon beam will be sufficiently intense such that the design sensitivity of the experiment can be achieved in a reasonable running time. The beam will be pulsed in order to allow detecting the conversion process without backgrounds from uninteresting physics processes. The required time structure will be achieved by exploiting the time structure in the circulating AGS beam, which is defined by the accelerating RF structure. The beam will be extracted while it is still captured in two RF buckets separated by half the circumference of the AGS, resulting in a pulse train separated by 1.35 μsec. The intensity required is 4×10^{13} protons (40 TP) to the experiment during each AGS cycle, with one

[4] AGS Final Safety Analysis Report, AGS Department, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York 11973, February 27, 1991.

[5] Programmed Improvements Of The Alternating Gradient Synchrotron Complex At Brookhaven National Laboratory Upton, New York, Environmental Assessment, U. S. Department Of Energy, DOE/EA #0909, November 1993.

cycle per second. Increased bunch intensity and techniques to extract a bunched beam at the required 8 GeV operating energy will be developed to meet these requirements. New magnet systems within the AGS will be installed and new operating techniques developed to ensure that protons circulate only in the desired RF buckets.

The planned running time for MECO is a total of 4000 hours. Construction and engineering runs will occur in the years FY04 through FY09. Physics running will occur from FY10 through FY12. Total annual high-intensity running periods of 27 weeks will be shared with the KOPIO experiment.

A new AGS extraction line in Building 912 will be built for MECO. Tasks include removing existing equipment, refurbishing existing magnets and power supplies, and installing modified beam-line magnets, vacuum systems, beam-monitoring instruments, and shielding. These activities will not only allow the experiment to go forward, but they will have the added benefit of reducing radiation burden due to reduced beam losses and better shielding. A radio-frequency modulated magnet of new design will be developed to remove protons outside the desired pulses and allow monitoring of the performance of the AGS. Two new Lambertson magnets will be built and installed. A counter system will be built to measure the number of protons not in the desired pulses.

No new buildings or tunnels will be constructed for the MECO experiment. Existing accelerator components will be upgraded or replaced. Existing experimental areas in Building 912 will be modified and used for the primary beam line, target area, beam dump and secondary beam line.

A new proton target in the A line in Building 912 is required to produce the pions that will decay and produce the muon beam. The MECO target will either be a gold or platinum metal-target. The target will be cooled by water, liquid nitrogen or liquid helium. A 50-ton copper and tungsten shield will be built surrounding the target to protect the superconducting magnet, in which the target is installed, from the heat and radiation produced in the target. The shield will be supported off a cylindrical "strong-back" that will also serve as part of the vacuum vessel in which the muons are produced and transported.

A new, large bore, 5 T peak-field superconducting-magnet, which is the called the production solenoid, will be built to contain the pions and muons inside the shield and direct them into a magnetic transport region. A set of magnets consisting of sections of solenoids and toroids, which is called the transport solenoid, will be designed and built. The transport solenoid will serve to guide the beam of muons to the detector region in the evacuated bore of a new superconducting magnet, which is called the detector solenoid. The detector solenoid serves to capture electrons from the conversion process. The detector solenoid guides electrons to a region containing particle detectors that, together with the magnet, comprise a magnetic spectrometer.

It is noted that for all planned magnets at C-AD including the 5 T magnet planned for MECO, C-AD will conduct an initial hazard assessment on all parts of the system that produce static magnetic fields. As with magnet assessments that have occurred for existing magnets at C-AD, the MECO magnet assessments will consist of identifying the source, surveying the magnetic field strength and exposure potential, and evaluating the results based on the BNL exposure limits in the SBMS Subject Area, Static Magnetic Field Safety. The C-AD will implement all appropriate administrative and work control requirements indicated in the Subject Area for the MECO magnets.

Three collimators in the straight sections of the transport solenoid will serve to restrict passage to muons of the correct charge and momentum range. A thin beryllium window, situated in the second collimator, will absorb anti-protons.

Located in the detector solenoid are the muon stopping-target, the tracker, the calorimeter, the muon beam-dump and various absorbers. The stopping target consists of thin Al or Ti foils suspended by low-mass supports. Thin, low-Z cylinders and cones at large radii are required to shield the electron detectors from low-energy protons emitted by the stopping target following muon capture. Some of these are lithium-doped to absorb neutrons. A muon beam-dump will be required to contain muons that have neither stopped in the target nor decayed.

Conversion electrons will be detected in a tracking detector installed in the constant field region of the detector solenoid. The energy of electrons will be measured in a calorimeter downstream of the tracker. The calorimeter detector will be a high-density crystal detector. Crystal materials will be GSO, BGO or $PbWO_4$.

A cosmic ray shield will be constructed to limit the background from cosmic ray muons interacting in the stopping target. It will consist of both passive shielding and an active scintillator-based veto detector.

A new enclosure for the front-end electronics will be built close to the experiment. An existing exterior building will be refurbished for use as the counting house. A data acquisition system and online computing facility will be assembled to record MECO data and allow for data quality control. This will be supported by several workstations for data monitoring and tape handling hardware for data recording. A sketch of the experimental layout in Building 912 is shown in Figures 3.1.1.o and 3.1.1.p.

Figure 3.1.1.o MECO Experiment in Building 912, Floor Layout and Detector Layout

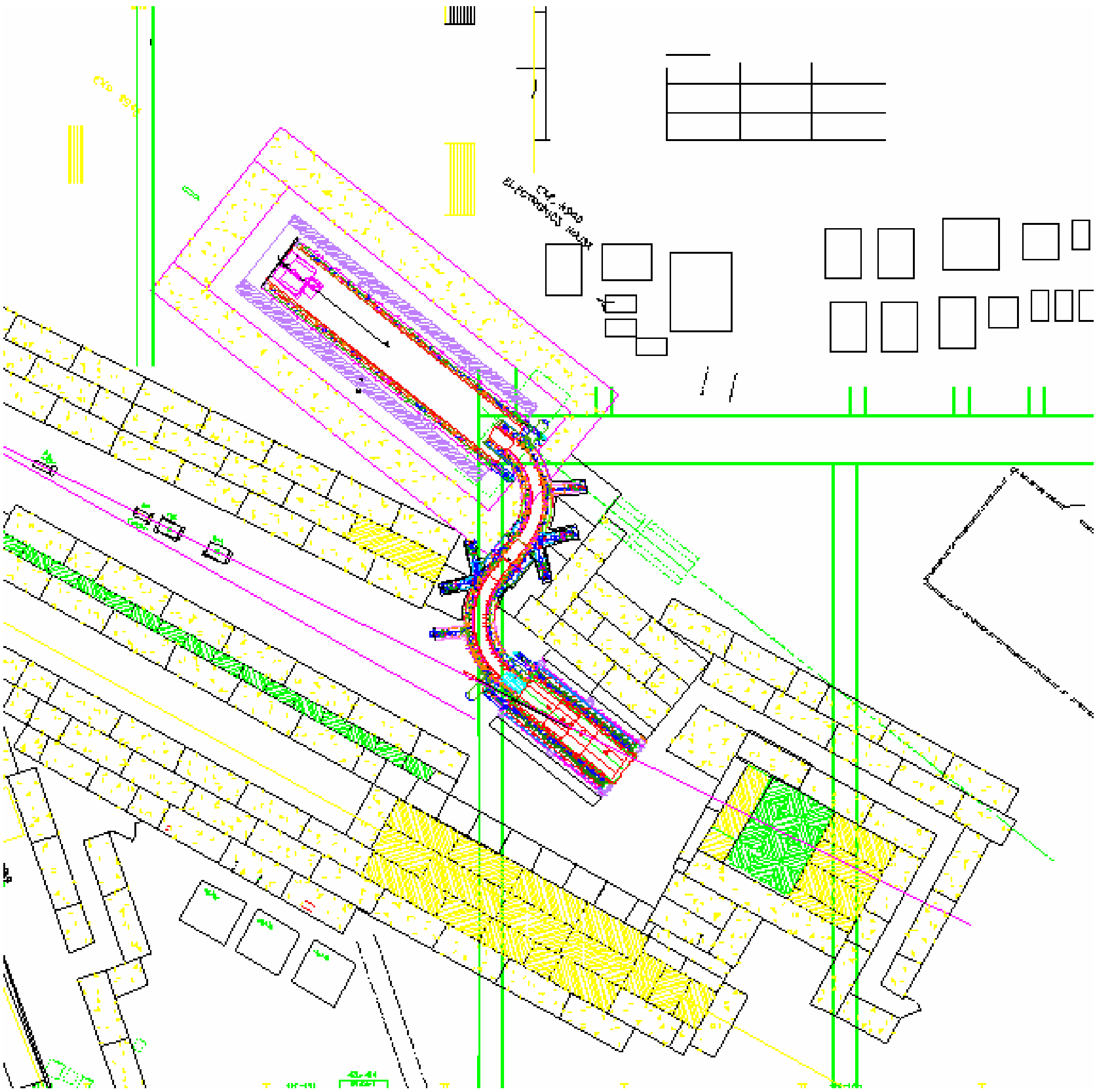
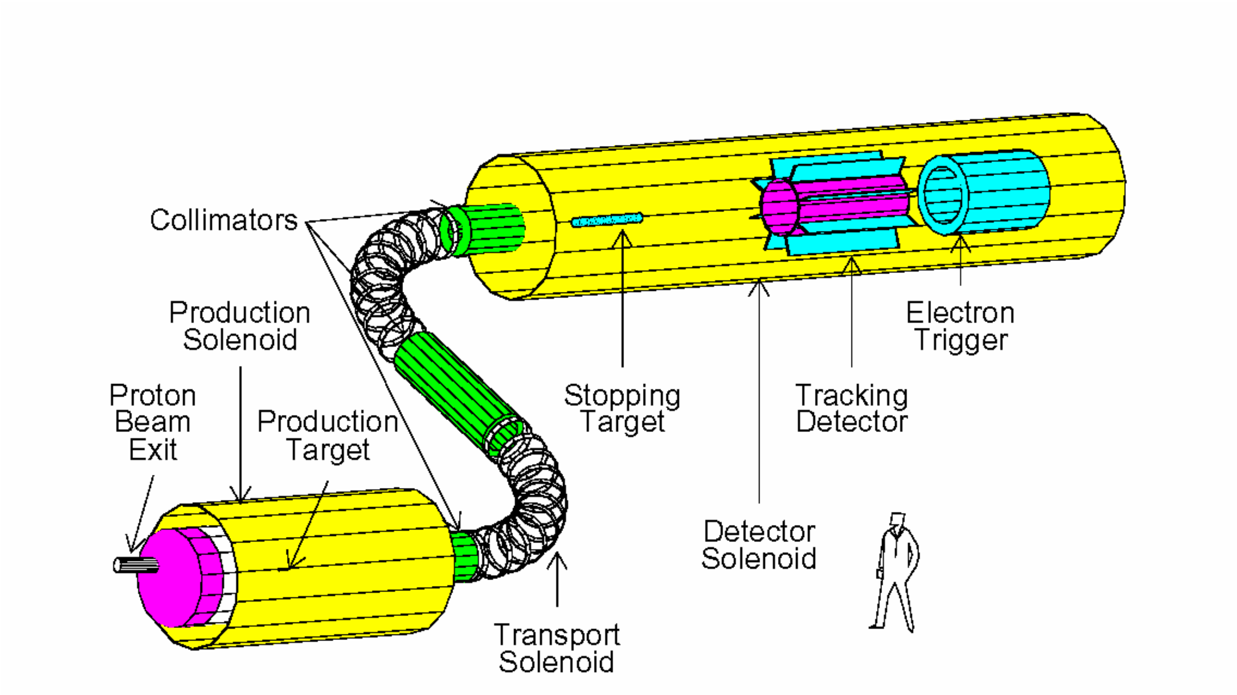


Figure 3.1.1.p MECO Solenoid Layout



Currently, CP violation[6] is recognized to be one of the most important outstanding issues in the study of elementary particle physics. The KOPIO component of the RSVP project

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[6] CP violation is the violation of the combined conservation laws associated with charge conjugation (C) and parity (P) by the weak nuclear force, which is responsible for reactions such as the decay of atomic nuclei. Charge conjugation is a mathematical operation that transforms a particle into an antiparticle, for example, changing the sign of the charge. Charge conjugation implies that every charged particle has an oppositely charged antimatter counterpart, or antiparticle. The antiparticle of an electrically neutral particle may be identical to the particle, as in the case of the neutral pion, or it may be distinct, as with the antineutron. Parity, or space inversion, is the reflection in the origin of the space coordinates of a particle or particle system; i.e., the three space dimensions x, y, and z become, respectively, -x, -y, and -z. Stated more concretely, parity conservation means that left and right and up and down are indistinguishable in the sense that an atomic nucleus throws off decay products up as often as down and left as often as right.

Kaons are unstable and are artificially spawned in K-antiK pairs amidst high-energy collisions. Kaons are born courtesy of the strong nuclear force, but the rest of their short lives are under control of the weak force, which compels a sort of split personality: neither the K nor anti-K leads a life of its own. Instead, each transforms repeatedly into the other. A more practical way of viewing the matter is to suppose that the K and anti-K are each a combination of two other particles, a short-lived entity called K_S which usually decays to two pions (giving K_S a CP value of +1) and a longer-lived entity, K_L, which decays into three pions (giving K_L a CP value of -1). This bit of bookkeeping enshrined the idea that CP is conserved.

proposes a measurement of direct CP violation via the decay of a neutral kaon into a single neutral pion and a neutrino–antineutrino pair. The single most incisive measurement in the study of CP violation is that of the branching ratio for $K_L^0 \rightarrow \pi^0 \upsilon\overline{\upsilon}$. Using current estimates for Standard Model parameters, it is expected to lie in the range 3.1 +/- 1.3x10^{-11}.

The $K_L^0 \rightarrow \pi^0 \upsilon\overline{\upsilon}$ decay mode is unique, in that it is completely dominated by direct CP-violation and is entirely governed by short distance physics involving the top quark. Theoretical uncertainties are extremely small. Thus its measurement will provide the standard against which all other measurements of CP violation will be compared, and even small deviations from the expectation value derived from other Standard Model measurements will unambiguously signal the presence of new physics.

The KOPIO experiment in Building 912 will employ an intense low-energy, time structured secondary K_L^0 beam. This intense beam, with its special characteristics, will be provided via an intense proton beam extracted from the AGS. Building 912 will house the high-intensity proton beam extracted from AGS in a heavily shielded transport-line. Building 912 will also house the proton-beam target area, the secondary neutral-kaon beam-line and the detector.

The high-intensity proton beam will be created by micro bunching the AGS proton beam via two RF cavities.

For the KOPIO experiment, three upgrades to the AGS will be carried out by a collaboration of accelerator experts at BNL and TRIUMF. These upgrades are: 1) extracting a micro-bunched proton-beam, 2) increasing the proton intensity by a factor of 1.5 or more to 10^{14} protons (100 TP) per AGS cycle, and 3) modifying a primary proton beam-line in Building 912 to bring the intense micro-bunched beam to a new kaon production target. Part of this work involves upgrades to the Booster extraction kicker magnet and the AGS injection kicker magnet to deliver the increased kick strength required for proper 2.0 GeV operation of the Booster extraction/injection system.

After acceleration in the AGS, the primary proton beam required by KOPIO will be resonantly extracted at 25.5 GeV over 2.4 seconds with a micro-bunch structure of less than 200 ps rms. It is anticipated that the full AGS intensity of 10^{14} protons (100 TP) per AGS acceleration cycle of 4.7 seconds will be available.

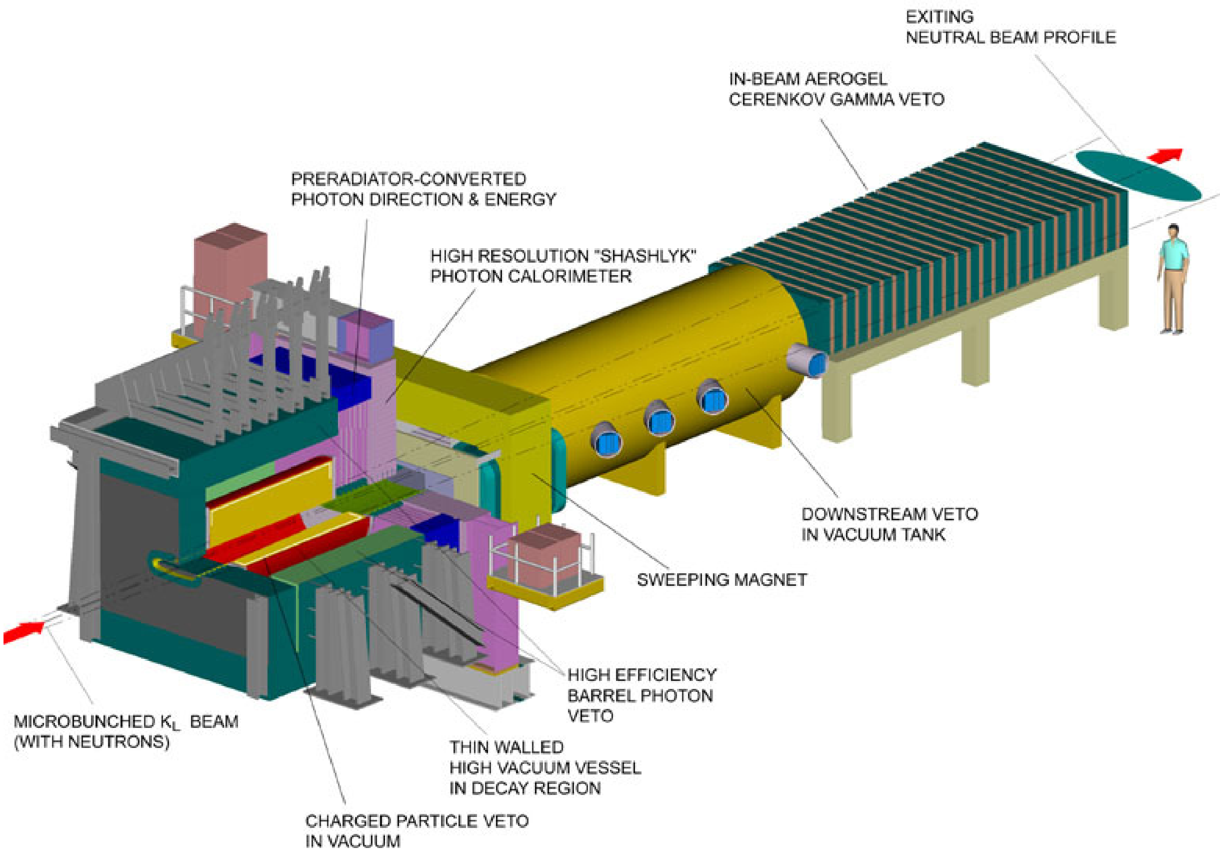
The planned running time for KOPIO is a total of 8000 hours. Construction and engineering runs will occur in the years FY04 through FY09. Physics running will occur from FY10 through FY14. In FY 10, 11 and 12 high-intensity running periods of 27 weeks will be shared with the KOPIO experiment. In FY 13 and 14, KOPIO will run without MECO.

No new buildings or tunnels will be constructed for the KOPIO experiment. Existing accelerator components will be upgraded or replaced with similar components that exist in the AGS and Booster. Existing experimental areas in Building 912 will be modified and used for the KOPIO primary beam-line, target area, beam dump and secondary beam line.

The micro-bunched beam extracted from AGS will be directed onto a B-line target to produce a neutral beam. The KOPIO target will be either gold or a platinum metal target cooled by water. These types of targets have been used successfully for many years at AGS. After the target, the beam-line elements necessary to collimate a neutral beam will be present. This includes a sweeper magnet to remove converted gamma rays and charged particles from the beam before entry into the KOPIO detector, and shielding to reduce unwanted backgrounds produced by the primary proton beam.

The detector will consists primarily of a vacuum system, a pre-radiator, a calorimeter system and a charged particle and photon veto systems (see Figure 3.1.1.q). The vacuum will consist of a high-vacuum segment, which will contain the decay events of interest, and a low-vacuum system, which will minimize downstream interactions. The pre-radiator system will consist of 32 modules constructed of dual-coordinate drift chambers, scintillators and layers of lead and copper. The pre-radiator will convert gamma rays and measure their directions. The calorimeter system will consist of lead-scintillator modules to measure energy. The photon veto will be a lead-scintillator sandwich that will be read out by wavelength-shifting fibers and phototubes. The charged particle veto will eliminate charged particles with very high efficiency, and the beam catcher will be a veto system used directly in the beam to detect and veto remaining photons.

Figure 3.1.1.q Relative Size of KOPIO Experimental Layout in Building 912



Existing utilities and roads in and around Building 912 will be used to support the MECO and KOPIO experiments. Existing power supply/utility buildings will be used. These buildings will house power distribution systems, power supplies, water pumping systems, instrumentation and controls for the MECO and KOPIO beam lines.

Electrical power is currently distributed around the site at 13.8 kV. Existing unit substations will transform the power into convenient voltages, typically 480 and 208/120 volts. Electrical power is divided into two major categories: conventional and experimental.

Conventional power encompasses building power for lighting and convenience power for heating, ventilation, air conditioning and miscellaneous equipment. Although there are no safety critical power needs, emergency power is be provided as required for smooth operations. Experimental power to AGS experimental areas feeds all the power supplies for magnets and associated equipment such as cooling-water pumps and cooling towers. All electric power distribution designs follow the requirements of the National Electrical Code and industry standards.

The cooling water systems for AGS experiments use cooling towers for primary heat rejection. The cooling water systems for tritiated water lines in AGS experiments are isolated, closed-loop cooling systems with heat exchangers. All tritiated water systems for AGS experiments comply with Suffolk County Article 12 requirements.

A shielded storage area is provided for radioactive component storage and repair of equipment used for AGS experiments. Modular concrete and steel shielding provides radiation shielding. Access to the proton target areas for installation and removal of the components is accomplished by removing the modular shielding. The design of radiological areas incorporates the as-low-as-reasonably-achievable (ALARA) radiation protection principles.

The un-interacted proton beams from KOPIO and MECO will exit to steel and concrete beam-dumps, which will be located inside Building 912.

The soil beneath the target areas and beam-dump areas is covered by Building 912. These activated soil areas are protected by a building roof, and a concrete floor with a water-resistant lining. The water-resistant lining is placed on the surface of the concrete floor over the target and beam-dump areas and it adds an additional barrier to prevent water infiltration into these soil areas.

The detector assemblies for KOPIO and MECO will utilize non-hazardous material configurations such as plastic or glass-type scintillator detectors with steel as the absorber materials.

The shielding policy for the KOPIO and MECO experiments is the same as that for the rest of the Collider-Accelerator facilities. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure that the shielding has been designed to:

- prevent contamination of the ground water
- limit annual site-boundary dose equivalent to less than 5 mrem
- limit annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities to less than 25 mrem
- limit dose equivalent to any area where access is not controlled to less than 20 mrem during a fault event
- limit the dose equivalent rate to radiation-workers in continuously occupied locations to ALARA but in no case would it be greater than 0.5 mrem in one hour or 20 mrem in one week
- limit the annual dose equivalent to radiation workers where occupancy is not continuous to ALARA, but in no case would it exceed 1000 mrem.

In addition to review and approval by the Radiation Safety Committee, final shield drawings are approved by the Radiation Safety Committee Chair or the C-AD ESHQ Associate

Chair. Shield drawings are verified by comparing the drawing to the actual configuration. Radiation surveys and fault studies are conducted after the shield has been constructed in order to verify the adequacy of the shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed and controlled by Collider-Accelerator Department procedures.

In addition to fixed-target experiments in Building 912, a fast proton beam may be extracted to perform fixed-target experiments in Building 919 and in the U line in Building 927. The Fast External Beam (FEB) exits the AGS via the H-10 extraction magnet. The fast beam enters the V line, which leads to the g-2 experiment, or it is directed to the U line, which is roughly parallel to the AGS to RHIC (AtR) transfer line, where additional fast beam experiments are performed. The heart of the g-2 experiment is a storage ring 21-feet in radius with superconducting coils providing a magnetic field of 1.47 T uniform to 1 part per million (ppm) over a toroidal volume 3.5 inches in minor diameter. Experiments in the U line are typical fixed target type surrounded by detectors, by means of which the interactions can be reconstructed.

The AtR line contains the aforementioned U and V lines plus the W, X and Y lines leading into RHIC. Beam bunches extracted from the AGS must pass through the AtR to get to the Collider. The AtR begins downstream of AGS fast extraction which comprises the G-10 extraction kicker magnet and H-10 extraction magnet. Before exiting the AGS, the beam undergoes a 4.25-inch bend through two dipole magnets accompanied by three quadrupoles for focusing. Bunches then traverse the U- Line. A stripping station is located in the U line where the last two electrons are removed from the not fully stripped heaviest ion species. The stripper is retracted when it is not needed. The first section of the AtR shares operation with U and V lines. The next section of the AtR, the W-Line, uses magnets to deflect the beam both horizontally and vertically. This deflection capability in the U-Line provides for flexibility in the choice of focusing parameters at the entrance of RHIC. It ensures symmetric behavior of the beam into the beam transfer branches, which are known as the X and Y arcs, which lead into the two rings in the RHIC tunnel. In AtR, a switching magnet is maintained to ensure a safe-off configuration whenever it is necessary to prevent transport of beam into the X or Y arcs. With the switching magnet de-energized, the beam will stop in a marble encased steel dump at the end of the W-Line, just before the X and Y arcs.

It is noted that the term ‘beam stop’ indicates the primary beam is stopped. Stops are used to prevent primary beam from traveling forward, and are used infrequently. Secondary particles created from stopping the primary beam at beam stops can and do move forward in the beam line. The term ‘beam dump’ is used to indicate a repository for both a primary beam and any secondary particles that contain most of the primary beam’s energy. Typical beam stops are small diameter metal objects several mean free paths in length that are sometimes cooled by water, whereas beam dumps are massive structures of concrete and steel sometimes as large as 12 feet x 12 feet x 50 feet.

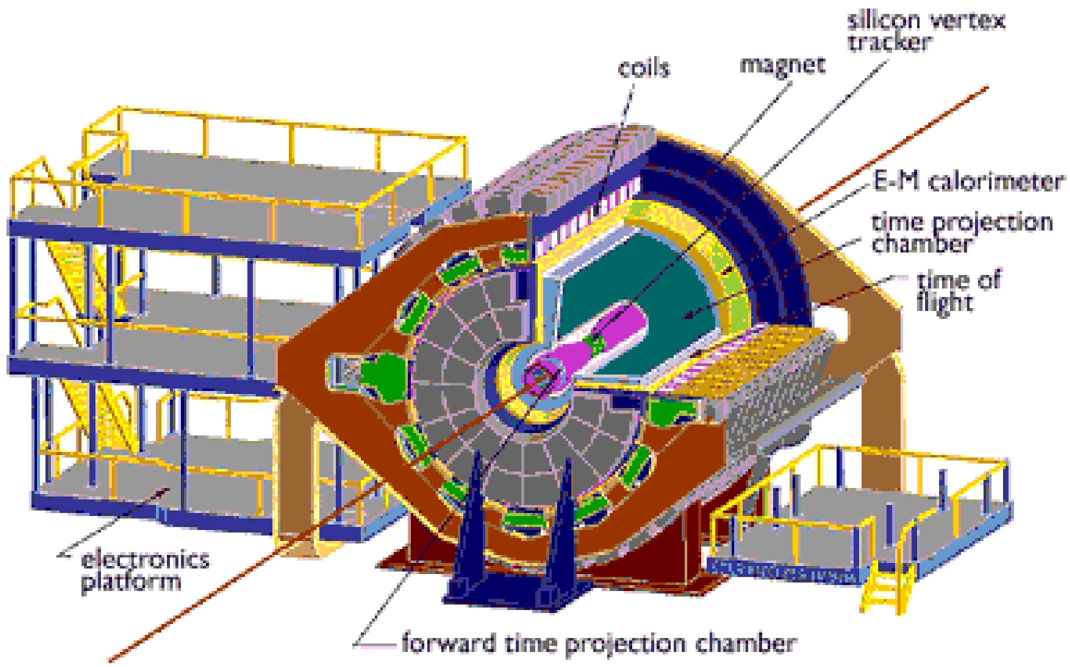
The RHIC machine itself is enclosed in a tunnel, 12 feet under the ground. Inside the two tubes shown in Figure 3.1.1.r, ion bunches travel around RHIC's 2.4-mile ring in opposite directions. The ion beams inside the two tubes are referred to as the yellow and blue beams. Each collider ring is made of hundreds of magnets. RHIC's magnets look different from those at the AGS because RHIC magnets are superconducting, using niobium titanium wire to carry the electrical current. Each magnet cylinder contains the steel magnet plus the cryogenic and electrical distribution systems. Like AGS, ion beams travel in a vacuum pipe in the middle. However, unlike AGS, super-insulation is used to wrap each magnet inside a cylinder, and beneath the insulation layers, super-cold helium is circulated to ensure temperatures stay at 4.5^o K. Like Booster and AGS, RHIC uses an RF system to give the circulating particles more energy.

Figure 3.1.1.r RHIC Tunnel Enclosure

RHIC's 2.4-mile ring has six intersection points where its two rings of accelerating magnets cross, allowing the particle beams to collide. The collisions produce the fleeting signals that, when captured by one of RHIC's experimental detectors, provide physicists with information about the most fundamental workings of nature. If RHIC's ring is thought of as a clock face, then the four current experiments are at 6 o'clock (STAR), 8 o'clock (PHENIX), 10 o'clock (PHOBOS) and 2 o'clock (BRAHMS). Additionally, there is a polarized-hydrogen-gas target (JET) in RHIC and it is used for elastic scattering measurements when polarized proton beams are circulating. The JET target is located at the 12 o'clock intersection point and the yellow and blue beams in RHIC are separated by ~10 mm instead of colliding. Only one beam at the time interacts with the JET target.

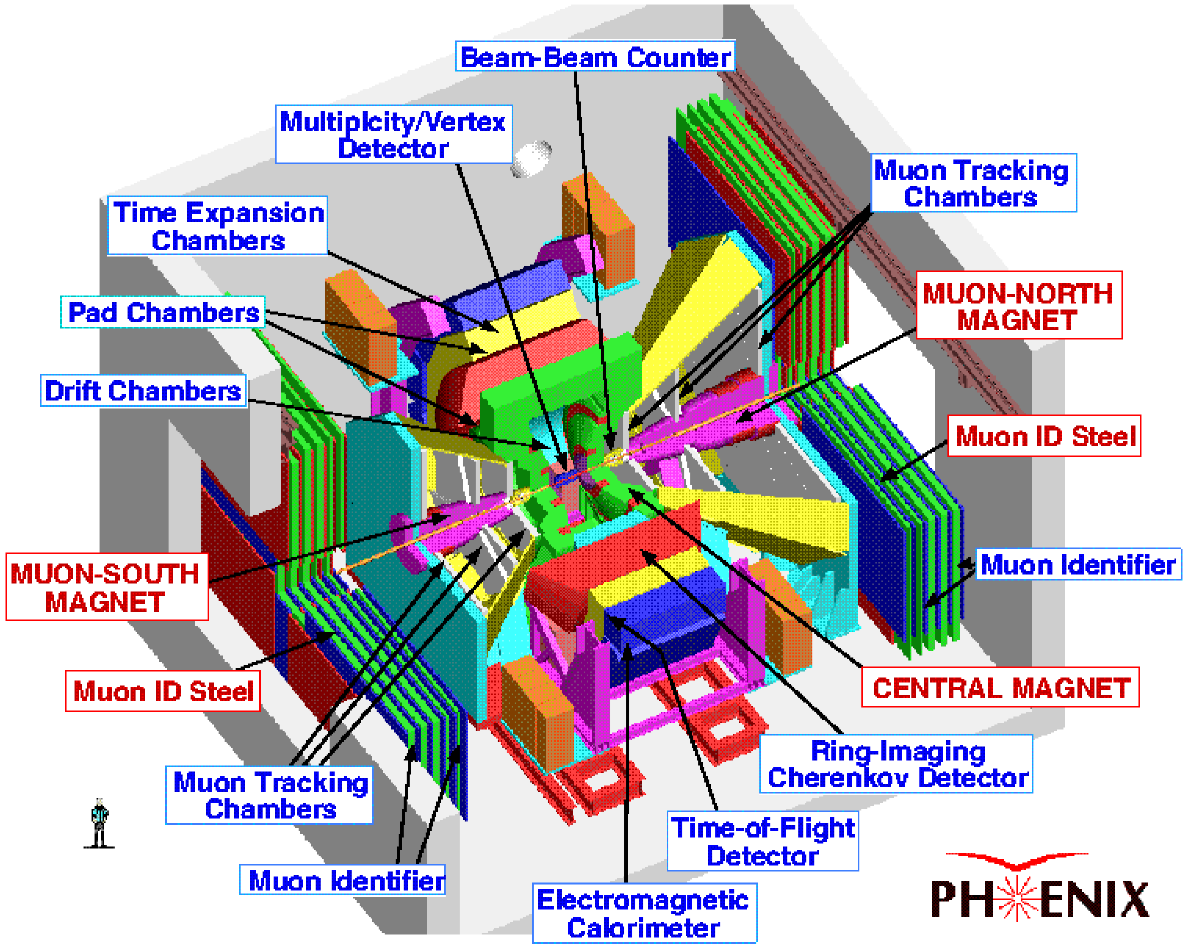
An example of a large experiment at RHIC is the Solenoidal Tracker at RHIC (STAR). This detector specializes in tracking the thousands of particles produced by each ion collision at RHIC. Weighing 1,200 tons and as large as a house, note ladder in image at left in Figure 3.1.1.s, STAR is a massive detector. It is used to search for signatures of the form of matter that RHIC was designed to create, which is the quark-gluon plasma. It is also used to investigate the behavior of matter at high energy densities by making measurements over a large area.

Figure 3.1.1.s STAR-Layout at a RHIC Intersection Region



Another example of a large experiment is the PHENIX experiment at RHIC. The PHENIX experiment aims at a broad investigation of many possible signatures of the Quark Gluon Plasma (QGP). It has a primary emphasis on leptons, both electrons and muons, as well as photons and hadrons. This is accomplished by an array of four spectrometer arms surrounding inner detectors that provide vertex, multiplicity and trigger information. PHENIX can simultaneously explore a wide variety of phenomena as a function of a few global variables. If the QGP exists it should manifest itself in several of these channels, and the appearance of multiple signals will underscore the reality of the phenomena being observed. Because of this broad approach, PHENIX is arguably one of the most complex detectors ever conceived (see Figure 3.1.1.t), encompassing 11 different detector technologies, as well as a sophisticated trigger and state of the art data acquisition system. The detector is comprised of two almost identical large aperture particle spectrometers at 90 degrees to the beam line, two almost identical spectrometers and identification systems for muon analysis along the beam lines, and two inner detectors. The core of PHENIX is provided by three large magnets. The collision point is surrounded by a central magnet (CM) which provides an approximately axial field. Along the beam line, two muon magnets (MM North and MM South) provide radial fields for analysis of muon tracks. These unique magnets have coils that excite a central conical steel piston. The magnetic flux is returned through a steel lampshade providing a radial field in the interior volume where tracking detectors are placed.

Figure 3.1.1.t PHENIX Experiment at RHIC



There are two electron accelerator systems planned for the 4 o'clock region of the RHIC ring, one system per ring, and they will be used to cool the ion beam in RHIC. An energy recovery Linac will be used to generate a 50-MeV electron beam that reduces the transverse energy of the circulating ions. Energy transfer between the 'cold' electron beam and the 'hot' ion beam will take place in a uniform solenoidal magnetic field in order to maintain particle alignment. Each electron accelerator consists of a photocathode RF electron gun "photo injector," a laser system to drive the photocathode, a superconducting Linac section, an electron-beam-transport consisting of an evacuated tube and various magnets and a beam-dump, and a large superconducting solenoid. The copper photo injector generates an electron beam of about 500 mA at 1.5 MeV or 100 mA at an energy of 2.5-MeV. The superconducting Linac energy reaches up to 50 MeV. An energy recovery of the Linac is used, so that the electrons are dumped at the photo injector energy. As plans for these electron-cooling accelerators develop, an update to this Safety Analysis Document will be developed.

3.1.2. Characterization of the Support Facilities

Accelerator operations in the Department require the following supporting facilities and supporting equipment:

- 6.2 miles of vacuum pipe
- 24 miles of cable tray
- several thousand electro-magnets
- compressors for the cryogenics systems
- 120+ buildings
- 45 electrical substations
- dozens of cooling towers
- 1.2 million ft^2 of office and laboratory space
- 1000 acres of land

- Several million tons of earth shielding
- 350,000 tons of concrete and iron shielding

Accelerator operations also require the following support: cooling operations, beam line assembly and disassembly, cryogenic system maintenance, electronics assembly operations, magnet cleaning operations, metal cleaning operations, plating operations, machine-shop operations and vacuum system operations.

Magnets are used to contain, bend, split and focus the beam and are located within the walls of the accelerator ring as well as within sections of the beam lines. There are numerous magnets maintained by the C-A Department, which use large amounts of electricity to create a strong magnetic field. Electrical cables attached to the magnets carry the electricity from the power supplies and rectifiers to the magnets. Due to the large amount of heat generated by the electricity that encounters resistance during use, a cooling water system is utilized to prevent the magnet from overheating.

The RHIC uses superconducting magnets to bend and focus the beam. The magnets in RHIC are cooled to 4.5 ^{0}K using supercritical helium gas. It is noted that helium will remain liquid at 1 atmosphere pressure provided the temperature does not rise above 4.2 ^{0}K. If the RHIC magnets are cooled with liquid helium and a high pulse of heat ensues in their operation, most of the helium must be vented to avoid large overpressures. To avoid this, the magnets operate with pumped supercritical helium gas, just above the critical temperature, which retains a large measure of the heat transfer properties of liquid helium, without the risk of overpressure. At cryogenic temperature of 4.5 ^{0}K, the magnets acquire superconducting properties, thereby greatly reducing the amount of electricity, which must be supplied to generate the magnetic field, and greatly reducing the amount of heat generated that must be removed to prevent the magnet from overheating.

The cryogenic system located in Buildings 1005R (Refrigerator Building) and 1005H (Compressor Building) supplies supercritical helium gas to cool the Collider magnets. The ring cryogenic system typically operates continuously up to 36 weeks per year. In simplified terms, the cryogenic systems operate as follows: gaseous helium is compressed and routed through carbon purifiers to remove any contaminants. The helium is then cooled through a heat exchanger and turbine expander system and both liquid helium and supercritical helium are produced. Vacuum pumps are used to evacuate the enclosed space surrounding the cryogenic equipment and piping to prevent convective heat transfer. Maintenance operations include the routine replacement of vacuum pump oil and o-rings, gaskets and seals, as required.

Screw-type compressors are utilized to compress the gaseous helium for subsequent expansion into liquid and supercritical helium. Oil for the compressors in Building 1005H is supplied from one 300-gallon oil tank, which is located inside the building.

In addition to the compressors used for compressing helium, the cryogenic system includes several compressors that are used as pumps and utility compressors. Each of the valve box locations has a utility compressor. The compressed helium supplied to the valve boxes is required to be dry and oil free. Thus, each is equipped with a dryer and oil mist and oil/water separator. These compressors do not hold large quantities of oil.

Other cryogenic system equipment includes the following: rotoflow control skids used to adjust the speed on the turbine expanders; heat exchangers used to cool the oil from the compressors; and, an oil purifying system is used to purify compressor oil in Building 1005H.

When helium gas flows through the screw compressors, some oil becomes entrained in the helium and must be removed prior to the helium entering the heat exchangers. From the compressor the helium passes through a series of coalescers, which are coarse filters, mist eliminators, which are fine filters, and molecular sieves, which is activated charcoal often referred to as charcoal beds.

During construction operations, magnets are removed from storage or an inactive beam line and mounted within their designated location. Cooling lines and electrical cables are attached to the magnets, run beneath the shielding walls where required and attached to the equipment. During disassembly operations, the magnets are placed in storage for future use. Cooling lines are disconnected from the cooling manifold and electrical cables are disconnected from the rectifiers and power supplies. Any worn or broken magnet coils, wiring or cooling manifolds are removed from the magnets and replaced with new parts or parts from storage. All worn or broken parts are surveyed for radioactivity to ensure proper disposal. Magnets, which may have become activated during use, depending on the location of the magnet, are placed in a Radioactive Materials Area, covered with shielding and left to "cool-off," which is also termed decay-in-storage. If a magnet component is to be discarded, then it is disposed of as radioactive waste.

There are many cooling water systems associated with the RHIC, AGS, Linac, Booster, NSRL and AGS primary/experimental beam lines. These systems are used for cooling magnets, electrical equipment, RF cavities, vacuum pumps, beam targets, compressors, buildings and various types of equipment. Equipment used to transfer or reject heat from the cooling water includes heat exchangers, chillers, evaporative coolers and cooling towers. The cooling water systems include closed loop, open loop and once through systems. As required, cooling water is supplied from the BNL potable water system and, if within acceptable limits, is discharged to the AGS and RHIC recharge basins, storm system or BNL sanitary system. Some cooling water systems have become activated due to interaction with the beam or radiation from the beam.

Radioactive water drained or collected from the various radioactive cooling water systems is transferred to one of three 7,000-gallon tanker trailers. These tankers, usually located at Building 974 can be moved by truck throughout the site to facilitate transferring of wastewater. The tankers are constructed of stainless steel and are parked within secondary containments when not being used to transfer water.

Steam or electric heat can be supplied to the tankers to slowly heat the wastewater and evaporate it. This wastewater treatment process has been reviewed against DOE Order 435.1, Radioactive Waste Management, and the process meets requirements. The vapor contains tritium from the activated cooling water systems. The emissions from the process have been assessed against NESHAPS requirements and radiation dose rates are well below levels that require continuous monitoring. Tanker water may be reused/recycled or evaporated. In recent years, as much as 20,000 gallons per year have been re-cycled while only a few thousand gallons per year were evaporated.

The beam lines are composed of aluminum or steel pipes through which the beam travels. The pipes along the primary beam lines and near the targets are activated by the beam, but those located along the secondary or experimental beam lines typically are not because the beam has less energy after hitting the targets. The experimental beam lines utilize magnets for containing and focusing the beam. During construction operations, the pipes are removed from storage or new piping is purchased and welded together to create a path to the experiment station. During disassembly operations, the sections of pipe are cut and stored in the C-A warehouse for future use following a “cooling off” period, if activated.

Various types of materials are welded during beam-line assembly operations including vacuum flanges, aluminum and stainless steel pipe, and magnet stands. In addition to welding, soldering is performed utilizing soft solder (tin/lead) and silver solder to connect electrical wires to various pieces of equipment.

The beam lines are constructed and disassembled, as required, in order to accommodate the particular accelerator or experiment. Beam lines typically consist of the beam line and magnets; electrical equipment and vacuum pumps; magnet cooling system; and concrete and metal shielding. Unless damaged beyond repair, equipment and material are reused by the C-A Department for the construction of new beam lines.

Magnets are periodically cleaned while in place to remove particulates such as scale and/or silt, which build-up in the piping bends and turns of the magnet cooling system. Particulates which build-up within the magnet cooling system can block cooling pipes and cause the magnet to overheat. The three techniques utilized for cleaning fouled or blocked magnets, in the order used, are backwashing, flushing with compressed nitrogen and flushing with an acid solution.

During operation with beam, large amounts of radiation are produced whenever the beam is split, collimated or stopped. Shielding is utilized to reduce or eliminate personnel and equipment exposure to radiation generated during beam operation. Shielding is required for the primary beam lines and target areas; however, it may not be required for the experimental beam lines (see Table 3.2.2.1, General Guideline for C-A Radiation Access Control System).

Shielding for the beam lines is typically reused from previous beam lines. Shielding is constructed of concrete block, steel plates and less frequently, lead bricks or other materials. The shape, thickness and placement of the shielding are determined for each application. Shielding is stacked on the floor around the beam line creating what is referred to as a "tunnel." Magnets, electrical cables, cooling water lines, vacuums pumps and the beam line are located within the tunnel. The remainder of the support equipment is located outside the tunnel and is therefore shielded from radiation produced by the beam. Cooling lines and electrical cables run in trenches beneath the tunnel walls to connect equipment located outside the tunnel. Shielding is offset stacked so that the gaps between the materials do not align to create a path through which radiation could pass. Large overhead cranes located within the building are utilized to move the shielding. These cranes are maintained by the BNL Plant Engineering (PE) Division.

Concrete blocks used for shielding were historically fabricated off-site utilizing "heavy" concrete. "Heavy" concrete is typically made of ilmenite-loaded concrete. Ilmenite is a natural substance. It is a mineral ($FeTiO_2$) with a high iron-content. Some new concrete shielding is fabricated on-site utilizing "light" 3,000-psi concrete. The shapes of the concrete blocks are designed for a particular location and use. When not needed immediately for shielding, the concrete blocks are stored in the outdoor Block Yard located north of Building 912 for reuse later.

Large steel plates and, less frequently, lead or tungsten bricks are utilized to provide shielding for the beam lines. While steel plates are utilized throughout, the lead or tungsten bricks are used as a collimator, which is a device for reducing the beam size by eliminating beam halo. These materials are stored for future use when not immediately needed for shielding. The steel plates are stored in the outdoor Steel Yard located adjacent to the Block Yard north of Building 912 and the lead bricks are stored within a small building located to east of Building 912 for reuse at a later date. Building 974 may also be used for material storage.

The beam line electrical systems consist of power supplies and rectifiers, which supply electricity to the magnets. The equipment is located outside of the shielding and is wired to the magnets within the shielding tunnel.

Rectifiers are utilized to convert incoming alternating current (AC) to direct current (DC), which is used to power the magnets. There are approximately 400 rectifiers used by the AGS alone. Some rectifiers contain capacitors that utilize dielectric oil containing polychlorinated biphenyls (PCBs). All rectifiers containing PCBs have been inventoried and are affixed with large warning labels stating, “Caution Contains PCBs.” All rectifiers, including those containing PCB capacitors, are checked for leaks prior to each run.

Devices referred to as “beam separators” require a significantly larger amount of electricity to operate and therefore use much larger power supplies. The high-voltage beam-separator power supplies contain approximately 500 gallons of dielectric oil. Due to the expansion of the oil from the heat being dissipated, large surge tanks are attached to the power supplies to accommodate the oil’s change in volume. The power supplies and surge tanks are located within secondary containment.

Vacuum pumps are utilized to evacuate the beam lines to prevent collisions of the beam with air molecules. The pumps are small capacity and typically contain less than 5 gallons of vacuum pump oil. Pumps located near floor drains are placed within secondary containment. Approximately half of the vacuums pumps are located within the beam line tunnels and half are located outside the tunnels depending on the available space. Periodically, vacuum pumps are brought into Building 911A, and to a lesser extent into Building 820, to be serviced. Servicing includes replacing equipment fluids and worn parts, and inspecting the equipment to ensure that it is operating properly. The Vacuum Lab area in 911A is also used for the enamalization of flanges. A parts steam cleaner is available in Building 820 to clean and remove dust from parts in storage.

The staff shops support the fabrication and maintenance of equipment, supplies and components used throughout the C-A Department. These shops consist of various machines used for the small-scale fabrication, assembly, maintenance, repair, and cleaning of metal and fiberglass equipment and parts. The machines used in the Staff Shops include milling machines, lathes, drill presses, band saws, grinders, shears, sanders, punches, breaks, benders, grit blasters and parts cleaners. Magnet refurbishment work is also conducted in Building 922, where worn or damaged magnet components are repaired or replaced. This operation involves soldering, metal cleaning, silver plating, coil maintenance, and cooling water hose and fitting repair.

Electronics assembly operations are conducted in Buildings 911A, 911C, 919B and 923 and are associated with the fabrication and operation of Collider-Accelerator support systems. Electronic assembly refers to the installation and interconnection of wires, mechanical connectors and electronic components onto printed circuit boards and within a piece of equipment.

Experiment stations are located at the end of the experimental beam lines or at interaction regions in the accelerators, and are constructed, maintained and disassembled by the investigators with assistance provided by the C-A Department. Experiment stations include detectors, instrumentation, data acquisition equipment and support systems. Experiment stations may also include magnets, power supplies to supply current to the magnet, PLC based controls and monitoring, buss systems to bring the power to the coils, and some experiments have hydraulic based moving systems for the magnets. The C-A Department typically assists the investigators with rigging and moving large pieces of equipment and shielding where required.

Typical gases used in particle detectors are nitrogen, carbon dioxide, helium, neon, xenon, argon, methane, ethane, isobutene, tetrafluoromethane and P-10. Nitrogen and carbon dioxide are stored as cryogenic liquids. Compressed inert gases such as carbon tetraflouride, helium, neon and xenon are stored in cylinders. Separately the liquefied hydrocarbons, ethane, methane and isobutane, are stored in cylinders. The C-A Department assists in the installation and disassembly of gas storage areas, gas mixing houses and gas piping to particle detectors.

Wherever large particle detectors reside, there are a variety of safety systems. The main safety systems include fire, smoke, flammable gas and oxygen deficiency (ODH) monitors. Some of these safety systems exist at up to three levels. The experimental areas are also serviced by HVAC systems that provide a continual fresh-air exchange, averting rising concentrations of leaked and locally vented gases. Emergency vent systems also exist and produce a high flow to dilute an airborne hazard. They are used to vent sudden, large gas leaks or smoke or may also be activated by the ODH alarm. The C-A Department assists in the installation, modification, replacement and disassembly of these safety systems.

3.2. Design Criteria and As-Built Characteristics

3.2.1. Design Criteria and As-Built Characteristics for Beam Instrumentation Systems

The purpose of the Beam Instrumentation Systems (BIS) is to minimize beam loss and to help provide the required beam on target. The C-A Department management has required that inadvertent beam loss occur at levels that are as low as reasonably achievable with operational, economic and community factors taken into account. As a minimum, the C-A Department has the following design criteria that the builders and managers of BIS must meet:

- set threshold acceleration, extraction and transport loss limits that activate alarms
- formally, approve changes to acceleration, extraction and transport loss limits as operations evolve
- identify appropriate instrumentation for measurement of the losses, and ensure measurements are reviewed at appropriate intervals in order to validate loss assumptions
- ensure alarm threshold values used by operations personnel are incorporated into the appropriate computerized controls programs
- ensure that written operations procedures contain loss limits
- ensure response by operators to alarms is clearly written in procedures; loss problems must be corrected within minutes; otherwise, operators must reduce the beam intensity to the affected area (for example, see OPM 6.1.0, ALARA Strategies for Tuning During Proton Operations. When a trigger threshold is exceeded, an alarm will appear on the Alarm

Display Task (ADT) monitor in MCR and a response will be required by the on-duty MCR Operations crew to reduce beam losses.)

- ensure authorization from the C-A Department Chair for prolonged high-loss operation with an alarm present
- assign the responsibility for maintaining loss-monitor systems
- verify the operability of beam current transformers and loss monitors used to determine operating efficiencies and losses at start-up of a running period
- perform residual radiation surveys to confirm loss assumptions

A general description of each type of beam-loss monitor in use at C-A Department follows. These devices are common to all C-A Department accelerators and experimental areas.

The “beam-loss monitor” is a device in which the collected charge is directly proportional to the beam loss. The unit consists of an ion chamber, an electrometer with a metering circuit and the necessary power supplies. It can detect radiation over the full range of potential beam loss but the measurement saturates in high-radiation fields. The ion chamber will measure ionizations from any penetrating radiation including x-rays, gamma rays, neutrons and high-energy particles such as pions and muons. There are two types used at C-A Department, one is a length of insulated heliax cable placed along the magnets that circulate or transport the beam. The cable is typically 1-inch in diameter with a 0.4-inch center conductor. The outer shield is biased with 200 volts, and there is a constant-flowing filling gas mixture of argon and ethane between the outer shield and center conductor. The other type is a sealed glass bottle 4-inches long, and 2-inches in diameter. The glass bottle is filled with argon, with two concentric nickel cylinders inside, one with a diameter of 0.25-inches and the other 1.5-inches. The outer cylinder operates at 1400 volts. An electrometer/integrator circuit measures the total charge collected by the center conductor of both types of detectors. Each glass-bottle beam-loss monitor is calibrated using a Cs-137 radiation source and an automated test and evaluation system. The characteristic response curves are fitted and loaded into the software application that displays the data.

The "beam-current monitor," which is also known as a "beam-current transformer," is a non-destructive device that is mounted around a ceramic break inserted in a metallic vacuum chamber, in an accelerator or beam line. It measures electric charge contained in a burst of beam, or the electric current generated by a series of beam pulses. The toroidal-shaped device is a ferromagnetic core that is made of high permeability metal tape or made of ferrite. The beam acts as a single primary turn that induces a voltage across a resistor that completes the secondary circuit that is made up of a number of turns of conductor. An additional turn is wound around the core and it is pulsed by a known current source in order to calibrate the system. A specifically designed electronics circuit generates a signal that is proportional to the beam charge passing through the detector.

The "ion chamber" is a semi-destructive detector used primarily in transport beam lines to measure the amount of low intensity charged particle beam passing through a defined time window. It is filled with argon-CO_2 (75%, 25%) at one atmosphere pressure. The voltage bias is set to +450 volts. There are four signal planes sandwiched between five high-voltage planes, and each has 0.635 cm gas-gap on either side. All eight gas-gaps for the four signal planes are summed and this yields a total ion-chamber gas length of 5.08 cm. Electron-ion pairs generated by charged particle beams passing through the gas volume are swept to respective planes by the bias voltage. The current from the signal plane is fed into a current-to-frequency converter module that generates counts that are monitored by the control system. Each count represents a known amount of current collected from the detector. A precision current source is used to calibrate the current-to-frequency converter. The charged particle's efficiency to generate an electron-ion pair is calculated based on widely accepted documented gas properties.

The "segmented wire ion chamber" (SWIC) is similar in design and function to the ion chamber described previously except that its purpose is to measure beam intensity in horizontal and vertical segments by using an array of thin signal wires in each plane instead of a single signal-plane. The voltage bias applied can be increased such that the voltage gradient near the signal wire is sufficient to cause electron multiplication resulting in net signal gain. This is an effective way to measure beam profiles for low-intensity beams. The charges collected on each wire are stored on an integrator circuit. Each channel is read out individually and displayed, and it shows a transverse profile of beam intensity verses position.

The "secondary emission chamber" (SEC) is used primarily in high-energy transport beam lines to measure the amount of high-intensity proton beam passing through. It consists of an evacuated chamber with five aluminum foil planes that are situated perpendicular to the beam trajectory. Three of the planes are high voltage bias, +450 volts, and two of the planes are for signal pickup. The configuration of these five planes is HV-S-HV-S-HV; that is, the signal (S) planes are sandwiched between adjacent high-voltage (HV) planes. As the beam passes through the foils, electrons are released from each of the foil surfaces with an efficiency of about 2.2% per proton. This interaction generates a current that is monitored by processing electronics. These electronics are calibrated based on the efficiency calculation derived from accepted documented beam/foil interactions. The SEC's are also cross-calibrated with beam current transformers when possible.

The "multiwire chamber," also known as a Harp, is used to measure horizontal and transverse beam profiles. As the name Harp implies, arrays of thin wires are suspended in both planes across the evacuated beam pipe aperture. Depending on the energy of the passing beam, either several electrons are knocked off or charge is absorbed resulting in a current flow. Each wire is connected to a processing electronics channel that generates a signal monitored by the controls system. A beam profile is reconstructed and displayed by a high-level application.

The "video-profile monitor," is also used to measure transverse beam profiles. It consists of a thin phosphor screen made of chromium-doped aluminum oxide, zinc cadmium sulfide or gadolinium oxy-sulfide doped with terbium. The thin screen is placed in the beam path. As the charged-particle beam passes through, the phosphor becomes luminescent; that is, at low temperatures a phosphor emits light in proportion to the transverse density of the beam. The light is collected by a nearby video camera, and the video signal is processed by a frame grabber in conjunction with a high-level control application, which calculates transverse beam-shape characteristics. The image is available to be displayed live on a video monitor. The shape of the beam can be tuned by the operation staff to desired parameters, and monitored to ensure transverse characteristics at a specific location.

The "beam telescope" is used to measure fixed targeting efficiency at high-energy proton primary targets. It consists of three scintillator-photomultiplier tube (PMT) assemblies positioned a distance away from the target, at a 90-degree angle from the incident proton beam. These assemblies are able to generate a signal when one minimum ionizing particle passes through the scintillator generating a photon that interacts with the PMT face. The resulting current is amplified by the PMT dynodes that are biased at 1400 volts. The three scintillators are aligned such that only a secondary particle leaving the target at a 90-degree angle will pass through all three detectors, which is similar to three lenses in a telescope, generating a triple coincidence in the signal processing electronics. The beam position and angle are typically scanned across the target until the ratio of beam intensity recorded by the SEC to coincidence counts recorded by the beam telescope is optimized.

"Beam position monitors" (BPMs) represent a class of devices all of which work on the same basic principle that is non-destructive position measurement by coupling to the electromagnetic fields of the passing bunch. There are quite a few different mechanical configurations throughout the C-A Department complex of accelerators and experimental areas. BPMs vary based on number of planes needed at a location, coupling frequency harmonic, aperture size and accelerator ring or transport application.

Beam intensity limiting devices are steel or tungsten "collimators and collimators are considered part of BIS. For example, the collimator used in the RHIC experimental systems is a mechanical device used to remove the beam halo to protect the experiments and accelerator components from excess radiation.

The Chief Mechanical and Chief Electrical Engineers review and approve these instrumentation systems. They use existing procedures in Chapter 9 of the C-A Department OPM. The Chief Engineers identify and mitigate hazards associated with beam instrumentation systems such as electrical shock, flammable gases, effluent releases, pressure and vacuum need.

Hazard mitigation is accomplished by ensuring the instrument design meets National Electric Code and SBMS standards.

The contents of the operating procedures for beam instrumentation systems are such that they instruct MCR operators to perform rudimentary operational checks of a subset of the accelerator instrumentation systems after the appropriate specialist reports that the apparatus is ready for testing. The subset of instruments focuses on those instruments that sense beams that have the potential to damage machine components and/or to create activation. The checkouts of these instruments are adequate to demonstrate normal operation. Checkouts are performed for Linac loss monitors and Fast Beam Inhibit system, Booster Ring loss monitors, AGS Ring loss monitors, circulating-beam monitors and beam position monitors. In the fixed target areas, SWICs are checked for heavy ion running, and SECs are checked for proton running. Additionally, target temperature monitors, phosphorescent screens or flags that are inserted for a few moments into the beam, and movable apertures such as beam collimators that could inadvertently intercept beam, are checked.

3.2.1.1.Beam Instrumentation for Linac

The beam instrumentation for the high intensity proton Linac are the devices used to monitor the beam while adjusting the beam transport through the Linac. They are required while tuning the RF systems to maintain beam quality, keep the beam loss as low as reasonably achievable and indicate the operating conditions. In addition, especially in the high intensity space charge dominated Booster, a transverse or longitudinal mis-match can cause beam halo, which can result in abnormal activation of the accelerator components. Some of the beam line instruments also provide an alert-system to protect the Linac by monitoring anomalously high radiation levels.

The types of the beam line instruments used are beam position monitors, beam current and profile monitors, beam phase monitors and beam loss monitors. The arrangement of these monitors not only achieves efficient beam observation for operations but also allows for beam studies.

The beam instruments at the Linac are arranged as follows:

The section between the ion sources and RFQ is called the low-energy beam transport (LEBT, beam energy is 35 keV). The high current H^- section is provided only with beam current monitoring. The beam energy is low enough that no radiation is produced, and no damage can be done even if full beam loss occurs. Steering and focusing of the beam can be optimized merely by measuring beam current before and after the RFQ, and optimizing RFQ transmission. In the beam line after the much lower intensity polarized H^- ion source, one has the additional capability of measuring beam profiles on a phosphor screen, and the current on one Faraday cup.

The medium-energy beam transport (MEBT, beam energy is 750 keV) is the ~6m connecting section between the RFQ and the Linac. This section needs to be tuned precisely in order to maximize transmission through the Linac. However, the energy is still low enough in the section that one does not produce any measurable radiation, and current loss can only cause minimal equipment damage. Tuning of this line includes setting properly the 12 focusing quadrupoles in the line, and setting the phases and amplitudes of the RF fields in the three buncher-cavities in the line. While the beam emittance, which is the angular spread of the beam at different transverse positions, can be measured with a special device at the entrance to the Linac, the line is primarily set by first setting elements to values calculated by computer model of the optics, and then fine-tuning. Fine-tuning is accomplished by measuring the beam current on the three current transformers in the line, and the current transformers after the early tanks of the Linac.

In the Linac itself, diagnostics include current transformers after each of the nine accelerating cavities, beam position monitors, which also provide beam phase information, after seven of the cavities, and beam profile measurements after six cavities via single horizontal and vertical wires. These wires are stepped through the beam, with the current reading from the wire recorded as a function of wire position. The wire is typically 0.004" diameter tungsten, so the beam current intercepted is extremely low. The current measured comes from secondary electron emission from the wire, thus the name of this device – Secondary Emission Monitor (SEM).

Initial setup of the Linac can be a complicated process, whereby one looks at inter-tank beam-phase information, as well as beam energy information measured by transporting the beam to the HEBT line (see the following paragraph). By measuring curves of the variation of beam phases and energy, as a function of the tanks' RF phases and amplitudes, and comparing with theoretical computer models of this dependence, one can set the Linac RF to match its design parameters. That is, the phase and voltage of the acceleration fields must produce a beam velocity profile through each cavity that matches the design profile, based on the mechanical properties of each drift tube. Similarly, the Linac drift tube quadrupoles are set to calculated values based on computer models. After this initial setup is done, fine adjustments are made to

RF phases, RF amplitudes, and quadrupole currents based on measured beam loss and beam energy spread measurements made in the HEBT line. One minimizes radiation from beam loss, using the LRM system described in the next paragraph. The initial setup of the Linac is done very infrequently, and a typical yearly turn-on for a run cycle involves only fine-tuning around values archived from the previous year's run.

In the high-energy beam transport (HEBT, beam energy is 200 MeV) section of the Linac, there are beam instruments both for Linac accelerator cavity tuning, and tuning of the beam through the various HEBT transport lines. Profiles can be measured throughout HEBT via about 10 distributed SEM monitors, as well as 4 multiwire profile monitors that give a full beam profile in a single pulse. In addition, there are several beam position monitors, and about 10 beam-current transformers. Once again, beam tuning typically starts with settings archived from previous runs, or computer model predictions. By looking at beam profiles, beam current, and beam loss, quadrupoles and steering dipoles are then adjusted to optimize beam transport and minimize beam loss. One additional diagnostic down the HEBT line allows one to measure beam momentum and momentum spread, which is useful for setting Linac cavity phases and amplitudes. There are both SEM and multiwire profile monitors located at a maximum dispersion point after an 18 degree bend in the HEBT line. Momentum can be determined by noting the dipole field required to center the beam on the profile monitor after the bend, while momentum spread is determined via measurement of the width of the beam profile. For higher resolution measurements, a partially degrading water-cooled slit can be inserted at the object point of this dispersive bend to better define the incoming beam size.

All along the Linac and HEBT, beam-loss monitors are used to identify the local beam loss, which provides an alert-system to protect against damage or component activation due to high beam loss. This is a distributed radiation-monitoring system that allows one to measure and to localize the inadvertent radiation produced by beam loss throughout the Linac. This “long radiation monitor” (LRM) system is a fast radiation measurement done during the beam pulse, and allows one to shut off beam within microseconds if the radiation level is above a preset threshold for any monitor. The detectors are approximately 10 m lengths of 7/8” diameter heliax cable, which are filled with argon to about 10 psig, and biased with approximately 100 V between the center conductor and shield. The detected signal is current resulting from ionization in the cable, ionization from beam-produced radiation. Approximately 30 cable sections provide complete coverage of the Linac and all of the high-energy beam transport sections. Signals from all detectors are brought back to the Linac control room where any one can be viewed on an oscilloscope to aid in beam tuning. In addition, all signals are sampled and held, allowing them to be displayed in the Linac control room as a histogram of all monitors, updated on each Linac beam pulse. All signals are also interfaced to the C-AD control system, so they can be viewed or logged from any control system console throughout the accelerator complex. Finally, and most importantly, all signals from the radiation detectors are fed into comparator circuits having individual reference voltages, thus allowing a tolerable loss pattern to be preset. If any LRM signal exceeds its allowable level, then the comparator output is used to turn off the beam within 5 microseconds, and display the loss location via a flashing light on a map board in the Linac control room.

3.2.1.2.Beam Instrumentation for TVDG

Various beam diagnostic devices are strategically located along the TVDG beam-lines to measure the optical properties and position of the beam. These include Faraday cups, beam-current transformers and beam-profile monitors. All necessary controls such as actuators and amplifiers are provided to make these instruments remotely operable via computer control.

Faraday cups are used for a variety of applications including the accurate monitoring of ion-beam currents. They are all metal and ceramic with a BNC feed-through and electrostatic or magnetic suppression. All beam interaction surfaces are tantalum. Because the Faraday cup absorbs all of the beam's energy, it cannot be used to measure beam current during an experimental run. It instead must be moved into the beam before an experiment, and then out of the way before the experiment can be run.

Unauthorized entry into any access-controlled zone at TVDG during beam operation will result in beam stoppage through the beam inhibit. Beam inhibit is caused by the insertion of redundant Faraday cups. These Faraday cups are utilized as beam stops for many operational conditions and are kept inserted whenever personnel enter the tunnel zones. One Faraday cup actuator is of spring-loaded fail-safe design that will revert to the inserted position in the unlikely event of power or compressed air loss.

The total beam current accelerated by the TVDG is self-limiting. Tandem van de Graaff accelerators, while capable of accelerating virtually any ion species, are very sensitive to the total charge available for the acceleration process. Beam currents from the ion source can be injected into the Tandem at a maximum of several micro-amps DC; accelerated beam currents measured at the higher-energy end of the accelerator are higher in terms of "charge" current due to the increase in charge state from stripping at the terminal. However, the total number of particles after acceleration is always somewhat reduced because the injection, acceleration and stripping processes have efficiencies less than unity. If one were to increase continually the ion source current much above a level of several micro-amps, then eventually, the terminal voltage will "sag' as a result of the inability of the charging system to supply sufficient charge. The consequence of the terminal voltage decrease is a reduction in beam energy, and the resulting lower energy beam cannot be transported around the TVDG analyzer magnet.

3.2.1.3.Beam Instrumentation for Booster and AGS

Instrumentation for the circulating-beam accelerators is combined with associated alarms and is used to provide an indication of an operational situation that could, if ignored, adversely affect the environment. One situation of concern is high-intensity proton operation in the Booster and AGS. Here the instrumentation and alarms guard against excessive beam losses that could result in equipment damage. In the machines that have to cope with high-intensity protons, the C-A OPM has a procedure, "ALARA Strategies for Tuning during Proton Operation," that lays out one system of beam measurements that result in limiting the amount of beam loss permitted during the acceleration and extraction processes. The procedure specifies the instruments that are required, such as current transformers and loss monitors, and the software used to generate alarms if specified levels of losses are measured. The beam-current levels to be respected are also specified by procedure. These levels are the responsibility of the liaison physicist for each step of the acceleration; that is, the Booster Liaison Physicist speaks for acceptable losses for beam coming into and accelerating in the Booster, the AGS Liaison Physicist speaks for the AGS. This instrumentation and procedure become relevant for beam intensities above 5×10^{12} protons per AGS cycle. The various levels that alarms constrain operations are based on experience both with beam losses and with equipment failures associated with beam losses. Alarm set points are consistent with reasonably efficient operation at highest intensity running levels.

3.2.1.4.Beam Instrumentation for RHIC and Collider Experimental Areas

The BIS associated with RHIC injection-lines, RHIC itself and RHIC experimental areas helps guard against moving to a situation where potential particle losses could add up to exceeding the limiting dose in an hour defined in the ASE. In RHIC and its injection lines, OPM procedure covers the instrumentation used to guard against excessive beam losses in certain areas. For example, relevant procedures include "RHIC Accelerator Safety Envelope Parameters," and "Procedure to Monitor Particle Losses in RHIC." The beam instrumentation systems involved are current transformers and loss monitors, which are in RHIC and its injection lines. The main strategy that keeps RHIC from approaching loss limits is a BIS that limits the number of particles injected into RHIC each hour. The details are spelled out for operators in a procedure that specifies the relevant software required to generate the required alarms. This type of "particle-monitoring" procedure is generated before each running period but may be re-generated quickly during periods when operations systems are revised. For example, if software is changed or instruments are replaced during shifts. This type of particle-monitoring procedure follows similar review and approval steps as the permanent procedures in the C-AD OPM; however, training requirements allow shift personnel to train on revised procedures without interrupting the accelerator schedule. In the RHIC BIS, the alarm levels set are simply derived from the radiation levels to be respected. The levels are verified from fault studies carried out to associate beam intensity lost with measured dose. The details of fault studies are documented by the C-A RSC.

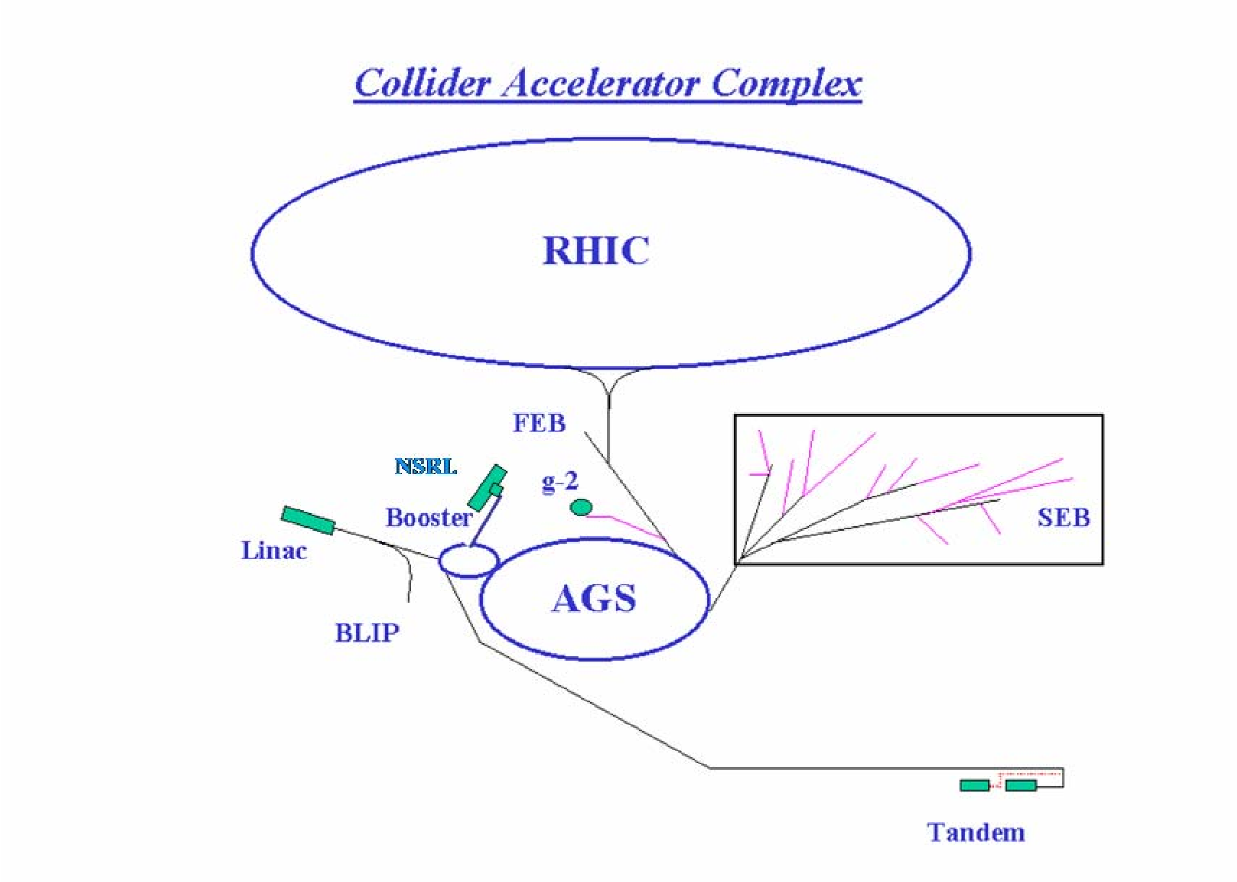
3.2.1.5.Beam Instrumentation for Experimental Beams Lines for Fixed Targets

The beam instrumentation systems (BIS) associated with the experimental beam lines associated with the fixed targets guard against moving to a situation where radiation damages equipment or causes unwarranted activation. Although radiation levels must also be respected in the experimental areas, the instrumentation systems used for personnel radiation protection are part of a higher quality, fail-safe system known as the Access Control System (ACS).

Booster receives and accelerates protons from Linac and heavy-ions from Tandem. Following acceleration, protons or heavy-ions may be slow extracted from Booster into the NSRL experimental area, or fast extracted into AGS, where particles are further accelerated to higher energies. Protons or heavy-ions may be “slow external beams” (SEB) from AGS into the switchyard or “fast external beams” (FEB) from AGS into a line that leads to the U and V fixed-target areas. FEB may also go to RHIC, where two opposing beams are injected, accelerated and collided. If slow-extracted high-intensity protons enter the switchyard located at the onset of the

SEB, then the proton beam is split twice into four primary beam lines that impinge onto special targets in order to produce secondary beam lines. In the case of heavy ions or polarized protons entering the switchyard in SEB, the beams proceed directly into experimental areas without producing secondary beams. See Figure 3.2.1.5.

Figure 3.2.1.5 Booster and AGS Extracted Beam Lines and the Collider



At the design stage for a beam line, beam-line optics and the placement of the respective magnets are determined using special beam-transport software that simulates the intended beam parameters. These software codes trace the beam passage through the electrostatic and magnetic elements from the source to the targets. Of primary concern is the delivery of beams with the proper characteristics assuring containment inside the beam pipe with minimal losses. Beam dumps are designed to assure that the beam is dissipated in a controlled fashion without adverse impact on the environment, such as unintended soil activation. At the design stage, beam-transport software helps determine the types of instrumentation that will be used for beam control; that is, the devices that make up a specific BIS.

In order to assess beam conditions and status in real time, the BIS for extracted beams and secondary beams is composed of several types of instruments. Beam instrumentation systems for measuring beam intensity consist of SECs, current transformers, ionization chambers and beam telescopes that view the targets. Beam instrumentation systems used to monitor beam position consist of florescent flags, beam-position monitors and SWICs. Beam losses inside the target caves are assessed using beam-position monitors. Particle fluence rate[7] outside the caves may be assessed indirectly in units of particles per cm^2 per second using "Chipmunk" radiation monitors; however, because of their role as a personnel safety interface, Chipmunks measure radiation levels directly in units of mrem/h and are part of the ACS and not the BIS.

The type of instrumentation used in the BIS for extracted beams is commensurate with application such as type of extraction, desired beam intensity and spot size. All BIS instrumentation is calibrated on a periodic basis, typically before each running period. The calibration and testing is performed by the Beam Components and Instrumentation Group who use procedures and checklists.

[7] Note: The name "flux density" has units of particles per cm^2 per second, and is a name that is sometimes used instead of "particle fluence rate."

Tuning and fault studies involve the use of the calibrated and tested BIS. Consistent with C-A Department ALARA policy, after a beam line is designed and components installed, the liaison physicist tunes the beam to confront design with reality and assure clean delivery of beam to the desired target. Fault studies are carried out and documented to ensure that beam enclosures are properly specified and constructed to contain any accidental radiation losses. It is noted that instrumentation from the Radiological Controls Division or instrumentation in the ACS are used for radiation measurements related to personnel protection, while BIS is used to tune the beam or to detect the location of beam loss.

While the beam line design and intended operation is subject to review by the RSC, the BIS is only subject to review by the liaison physicist since the BIS serves only to protect equipment and to tune the desired beam in order to meet an experimenter's needs. On the other hand, the RSC reviews ACS instrumentation that is specifically designed to assure that proper beam operations minimally influence personnel or the environment. For example, Nuclear Measurements Corporation (NMC) instruments, which have scintillation paddle detectors, are positioned directly in the beam with their output calibrated versus beam intensity. Chipmunks, which are tissue equivalent gas-filled ion chambers, are positioned at potentially occupied locations outside the shielding, and their output logged. Both NMCs and Chipmunks are interlocked to shut down the beam at preset RSC-approved radiation levels in case beam strays due to magnet failure. In addition, current comparators are used by the RSC to make certain that a particular beam stays in its particular channel or that it does not exceed a certain set momentum.

The liaison physicist, who is responsible for tuning the beam using the BIS, is also responsible to generate check-off lists that ensure ACS instruments are in place before tuning begins. The RSC Chair and C-A Department Chair or designees approve these check-off lists for each beam line, and MCR operators must possess a completed checklist before resetting the line for beam operations.

In order to detect long-term low-level losses, daily radiation surveys are carried out around the perimeters of operating beam lines. Low-level beam losses may be tolerated by the BIS or ACS but may not be ALARA. Routine radiation surveys are performed by RCTs using portable calibrated instruments designed to detect neutrons and photons. The surveys are logged and kept for future reference. Beam operations data, which includes these radiation surveys, are monitored by the liaison physicist responsible for a specific beam line on a periodic basis to evaluate beam status, to assure that the desired beam tune is being adhered to and to ensure that the beam line is operating with minimal losses. Procedures that help ensure this practice is carried out by liaison physicists, procedures such as such as "Transport Beam Tune Maintenance," are kept up-to-date in the C-A Department OPM.

3.2.2.Design Criteria and As-Built Characteristics for Access/Beam Control Systems

3.2.2.1.General Design Criteria for Access Control System (ACS)

This section describes the general design criteria for the access/beam control system (ACS). The Department's 'classification' scheme for all radiological areas at C-A Department defines the nature and extent of the access/beam control systems. The ACS prohibits access or limits the radiation dose when the radiological areas are accessed. Table 3.2.2.1 delineates the access, enclosure and minimum system requirements, for each C-A Department ‘classification,’ and takes into account the potential levels of radiation during normal operations, and the potential increases in radiation levels with abnormal conditions.

The three allowed access modes are procedural access, Restricted Access and Controlled Access. The control of each allowed access mode, except procedural access, is under the purview of Main Control Room (MCR) operators who select the appropriate mode. Procedural access requires management approval.

In the Restricted Access mode, the doors to the enclosure are locked. Personnel require a key or a magnetic card for entry. TLDs are required for radiation fields greater than 5 mrem/h, and in radiation fields greater than 100 mrem/h, digital alarming dosimeters are required. For unescorted entry, personnel are required to have appropriate radiological training and Collider-Accelerator Department area-specific access training. Personnel meeting these requirements may enter the area unescorted if they also meet the conditions of the applicable Radiation Work Permit (RWP) when access is allowed to the enclosure.

In the Controlled Access mode, MCR Operators ‘sweep’ the area clear of all personnel, then allow trained and authorized persons to enter and exit the area while keeping a log-in/log-out record and a gate watch. The operator may be stationed at the gate or be remotely located and able to view an entrant via video camera. The operator controls the opening of the gate. In some cases, bio-identification access systems are used to log entry and exit into an area under Controlled Access and to permit the individual to take a key from a key tree. In Controlled

Access mode, an Operator is permitted to reset an area for beam without a re-sweep provided the gate watcher or bio-identification unit ensures all personnel have logged-out of the area.

MCR Operators can place an enclosure in access-prohibited mode and subsequently enable the beam after the enclosure is swept and the area resets are complete. Both the local resets and remote resets must be complete. An area-reset state ensures that the sweep status of the enclosure has not changed. Primary beam enclosures are enclosures containing uncollided beam capable of producing whole-body dose rates in excess of 50 rem/h. Secondary beam enclosures are enclosures that contain the beams resulting from primary beam interactions at fixed targets. The hazard from secondary beams may vary from being as high as from the primary beam itself, to levels not requiring access controls. Upon MCR reset of a beam enclosure, a visual warning in the enclosure is displayed, an audible warning sounds and a timer starts before beam can enter the enclosure. The timer varies for each accelerator, and it ranges from 30 to 90 seconds. If a person remains inside a reset area, he/she can use emergency-stops (crash-buttons or crash-cords), which are located throughout the beam enclosures. They are visible under emergency lighting conditions. An emergency stop requires local resetting. The status of emergency-stops is monitored in the MCR.

The term beam-enabled indicates functional status and the presence of beam or the potential presence of beam. Under this condition, there is the potential to create undesired radiation in nearby occupied areas. Access to areas that are contiguous to beam-enabled areas are also evaluated and classified by the RSC, and appropriate access controls are established.

In the access-prohibited mode, areas may be fenced with locked gates, or if levels could exceed 50 rem/hr (C-A Department Classes I and II), the access/beam control system disables slide bolts or electric strikes on all access doors. In Class I and II areas, all access paths have a minimum of two sensors to detect an open door and disable the radiation source.

For Class I and II areas, an interlock trip causes two independent critical devices to disable the radiation source. Additionally, each access gate is equipped with a bolt-home micro-switch to indicate that the gate is locked. The status of these gates is monitored from the MCR. For Class III and IV areas, the gates must be locked and have a sensor that monitors if the gate is closed or opened. If opened, the ACS disables the beam. For Class V and VI areas, gates are locked, but not monitored, when access is prohibited.

The access control system inhibits beam via hardwired critical devices or critical circuits. The terms dual or redundant means two independent critical devices or interlock systems are used or required. Each device or interlock system is isolated from the other to perform a similar safety function, such that any single failure will not result in the loss of protection. Fail-safe means that predictable failures of the system leave the ACS in a safe mode. The de-energized state of relays used in the ACS is the fail-safe state.

Active types of access control systems are either electronic devices such as radiation monitors, or written procedures. Procedural access is an access where requirements are enumerated in the RWP and other work documents in order to make the area safe for occupancy. Active devices, on the other hand, make the area safe when they sense unwarranted levels of radiation or beam current, or when they sense excursions outside the preset limits for electrical signals. Hardwired normally refers to mechanical switches, mechanical devices and electromechanical relays. The RSC has the authority to classify active devices as hardwired devices if the design is sufficiently robust and appropriate engineering reviews are done.

Currently, three active devices are classified as “hardwired” by the RSC: (1) interlocking chipmunk area-radiation monitors, (2) interlocking Nuclear Measurements Corporation (NMC) units and (3) Rochester Instruments, Inc. "Fail-Safe Trip" units.

A bypass is a temporary task-specific defeat of a single interlock function or group of functions. Modification of the ACS means reconfiguring the interlock system for routine operations. Modification and bypass may follow different administrative approval processes at C-A Department. While documentation of bypasses and modifications must be in accord with procedures located in OPM Chapter 4, bypasses may also be performed under the purview of the RSC using fault study procedures in OPM Chapter 9.

There are five basic design criteria for the ACS that applies to all C-A Department beam enclosures:

- either the radiation is disabled or the related access control area is secured
- only wires, switches, relays, programmable logic controllers (PLCs) and RSC approved active fail-safe devices are used in the critical circuits of the system
- the system is designed to be fail-safe; for example, where relays are used, the de-energized state of a relay is the fail-safe state
- redundant critical devices are used to disable the beam and redundant interlocks are used to secure the area if the dose rate can exceed 50 rem/h
- if a beam fails to be disabled as required by the state of its related access control area, then the upstream beam is disabled; that is, the access controls have backup or what is sometimes termed “reach-back”

The RSC reviews and approves changes to the ACS. They approve the critical devices and they establish the conditions that the ACS must monitor. For example, they approve electric current in beam elements, the position of moveable beam-components or the position of access gates. The RSC establishes the alarm level and interlock level for Chipmunk area radiation monitors that may be interfaced with the ACS.

During commissioning periods for new or modified accelerator facilities, radiation surveys and fault studies are conducted by the RSC to verify the adequacy of the shielding and the radiological area classification. The resulting area classifications, which are confirmed by direct radiation measurements as opposed to calculations, confirm the appropriateness of the as-built ACS. The relationship between area classification and ACS requirements is indicated in Table 3.2.2.1. Note the term ‘active’ means an interlocking radiation monitor or other electronic device of some approved type (see C-AD OPM 9.1.11 for additional information). The table shows the following:

- Column 1 – the C-A classification of an area and corresponding 10CFR835 name for the area
- Column 2 - the corresponding radiation dose rate or range of dose rates
- Column 3 - the equivalent radiation levels as in column 2 but in terms of beam-fluence rate
- Column 4 - the training and access requirements to enter the area when beam is enabled
- Column 5 - the sweep and reset authority for the area required to enable beam
- Column 6 - the area enclosure or barrier requirements
- Column 7 - the C-A classification for normal operations and the *C-A classification if the beam fluence rate could be accidentally increased to a higher C-A Class*

- Column 8 – the minimum Access Control System hardware for normal operations and t*he minimum Access Control System hardware if the beam fluence rate could be accidentally increased to a higher C-A Class*
- Column 9 – The purpose of the Access control System for normal operations and the purpose of the Access Control System *if the beam fluence rate could be accidentally increased to a higher C-A Class*

The procedure for review of new or modified ACS designs requires the liaison physicist assigned to a beam line or accelerator to describe the radiation issues and protection methods to the RSC in a written description. The RSC reviews and makes recommendations on the interlock system with special attention to defining the classification of the area and the corresponding ACS. The RSC assigns a subcommittee to review the final interlock design upon its completion. Meeting minutes or a memorandum noting the details of the design as approved by the sub-committee are distributed to all RSC members. A full RSC review of the logic is done if an RSC member finds the recommended solution to be deficient. The approved logic diagram or state table, and the approved wiring diagram become controlled documents.

Table 3.2.2.1 General Guideline for C-A Radiation Access-Control System Classification and Application

ACS –Access Control System; HFD-Hardwire, fail-safe, dual; HF-Hardwire, fail-safe; AFD-Active, fail-safe, dual; AF-Active, fail-safe; H-Hardwired; AD-Active, Dual; A-Active

C-A Class Area Name with Access as per 10CFR835	Radiation Level (Allowed potential whole body dose with access)	Equivalent 30 GeV Large Beam Proton Fluence Rate,[a,b,c] (cm^{-2} h^{-1})	Access When Beam Enabled	Sweep/Reset Authority	Area Enclosure	C-A Class (Radiation Level) *C-A Class without Access*	Minimum ACS *Additional ACS at this Class Level*	Purpose of ACS for Operational Class *Purpose of ACS for Class*
Class I Very High Radiation Area -	>500 rad/hr [a]	$>3.9x10^9$	Absolute Prohibition	MCR Operator or Radiation Safety Committee (RSC) Designate	Impregnable Enclosure, Dual Interlocked Gates	I *Not Applicable*	HFD *Not Applicable*	Preventing Access or Beam Enabled *Not Applicable*
Class II High Radiation Area-	<500 rad/hr >50 rem/hr	$<3.9x10^9$ $>1.1x10^8$	Special Radiological Control Division (RCD) Approved Procedure	RSC Designate	Fully Enclosed, Dual Interlocked Gates	II *I*	HFD *Not Specified*	Controlling Access or Beam Enabled *Preventing exposure to these levels*
Class III High Radiation Area -	<50 rem/hr >5 rem/hr	$<1.1x10^8$ $>1.1x10^7$	RCD Technician Supervision	RSC Designate	Walls or Fences, Interlocked Gates	III *II* *I*	HF *AF* *HF*	Controlling Access or Beam Enabled *Preventing exposure to these levels* *Preventing exposure to these levels*
Class IV High Radiation Area	<5 rem/hr >0.1 rem/hr	$<1.1x10^7$ $>2.3x10^5$	Individual Authorized by the RSC	Individual User May Be Authorized by the RSC	Walls or Fences, Locked Gates	IV *III* *II* *I*	H *AF* *HF* *HFD*	Control Access or Beam Enable *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class V Radiation Area	<0.1 rem/hr >0.005 rem/hr	$<2.3x10^5$ $>1.1x10^4$	Radiation Worker or Visitor Escorted by Radiation Worker	When Required, Individual User Authorized by the RSC	Fences or, Ropes; Radiation Warning Signs Every 40 ft	V *IV* *III* *II, I*	A *A* *HF* *HFD*	Alarm on Excessive Radiation *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*
Class VI Controlled Area	<0.005 rem/hr >0.00005 rem/hr	$<1.1x10^4$ $>1.1x10^2$	General Employee Radiation Trained Individual or Escorted Visitor	Not Required	Signs, Fences or, Ropes at Perimeter; Posted at Entrances	VI *V* *IV* *III* *II, I*	A *A* *H* *HF* *HFD*	None *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels* *Preventing exposure to these levels*

a See C-A OPM procedures for small beam sizes.
b If the absorbed dose rate is 500 rad/hr or greater, the area is named a “Very High Radiation Area” as per 10CFR835.
c This is the fluence rate from a beam of 30-GeV hadrons with size greater than 1000 cm^2. It corresponds to the dose rate listed in column two.

3.2.2.2. Example As-Built Characteristics for the Access/Beam Control Systems

3.2.2.2.1.NASA Space Radiation Laboratory (NSRL)

The Access Control System (ACS) for the NSRL is an example of the type of ACS installed at C-AD facilities. The NSRL ACS contains gates, labyrinth entrances, video cameras, bio-scanners, etc. that are typical of modern systems. The NSRL ACS controls four gates that lead to the beam line or Target Room:

- labyrinth entrance from the Support Laboratories (BGE1)
- labyrinth entrance from the beam-line shield door (BGE2)
- internal isolation gate at the upstream end near the Target Room (BGI1)
- internal gate at the upstream end of the beam line (BGI2)

BGE1 and BGE2 are normal external access gates and are instrumented to disable NASA Space Radiation Laboratory extracted beam. BGE2 is designed to allow beam line access for large items; for example, a vacuum leak checking station. BGI1 allows unrestricted egress from the NSRL tunnel into the Target Room but requires, in some access control configurations, a Controlled Access (CA) key and simultaneous release from the Main Control Room for movement from the Target Room to the NSRL tunnel. BGI2 isolates the long straight section of the NSRL tunnel from the beam line segment contiguous with the Booster penetration. A small shield-labyrinth is used in this region to mitigate the impact of beam loss in the Booster ring. BGI2 is instrumented to disable the Booster injected beam for both the Linac and the Tandem.

Figure 3.2.2.2.10.a shows the layout of Access Control System for NSRL. The Figure shows gates (BG#), video cameras, bio-scanning device, key tree, beam-imminent warning devices (CB#), sweep zones (NASA Space Radiation Laboratory-Z#) and crash operators (CO#). A picture of the system at the entrance to the interlocked areas is shown in Figure 3.2.2.10.b. Each person entering the target room during a run has primary responsibility for his or her own safety. Access to the target area is gained using a card reader or the iris-scanner/token-key depending on the operational state of the beam line. Only properly trained individuals can access this area. There are two operational states or modes of access defined as, "Restricted" or "Controlled." When the target room is in a "Restricted Access" state, which is evinced by a green state-light (see '1' in Figure 3.2.2.2.10.b), the doors to the target room will open with a placement of an access card on the card reader. This is the normal state of the system when beam is not being used for Radiobiology experiments. When the target room is in a "Controlled Access" state, which is evinced by an orange state-light (1), access is granted only to those with appropriate training, a key from the key tree and with a simultaneous release of the gate locks by both the user and a Main Control Room (MCR) Operator. This mode is the usual mode of access during radiobiology runs. The beam is interrupted for several minutes while the access is made then returned once the access is complete. The verification-of-training is achieved by the iris-scanner (see '2' in Figure 3.2.2.2.10.b), which, upon recognition, will display the user's name in the control room. This allows the MCR Operator to write down the user's name in the log sheet, and it will release one of the token-keys (see '3' in Figure 3.2.2.2.10.b) to the user. The key is then inserted into the key release, which is shown as '4' in Figure 3.2.2.10.b. The user carries

the token key into the area. The beam cannot be operated until the key is re-captured in the token-key box and the interlock is reset by MCR.

Figure 3.2.2.2.10.a NSRL Access Control System Layout

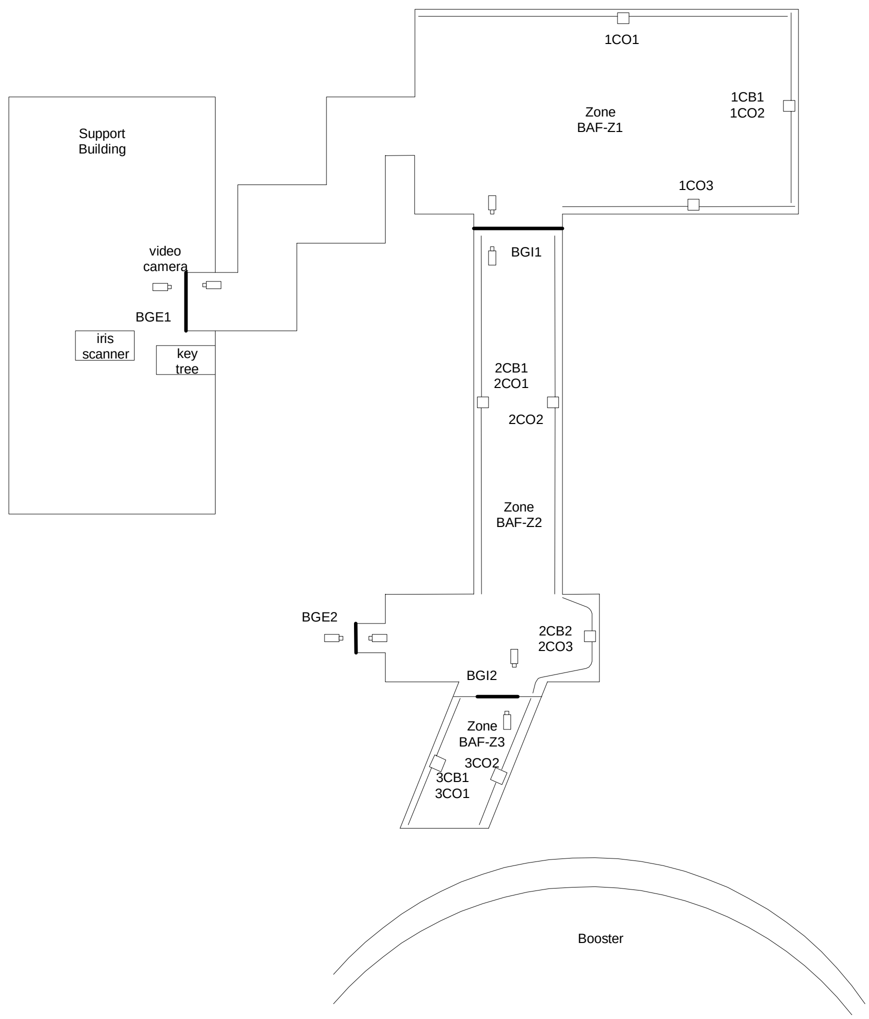
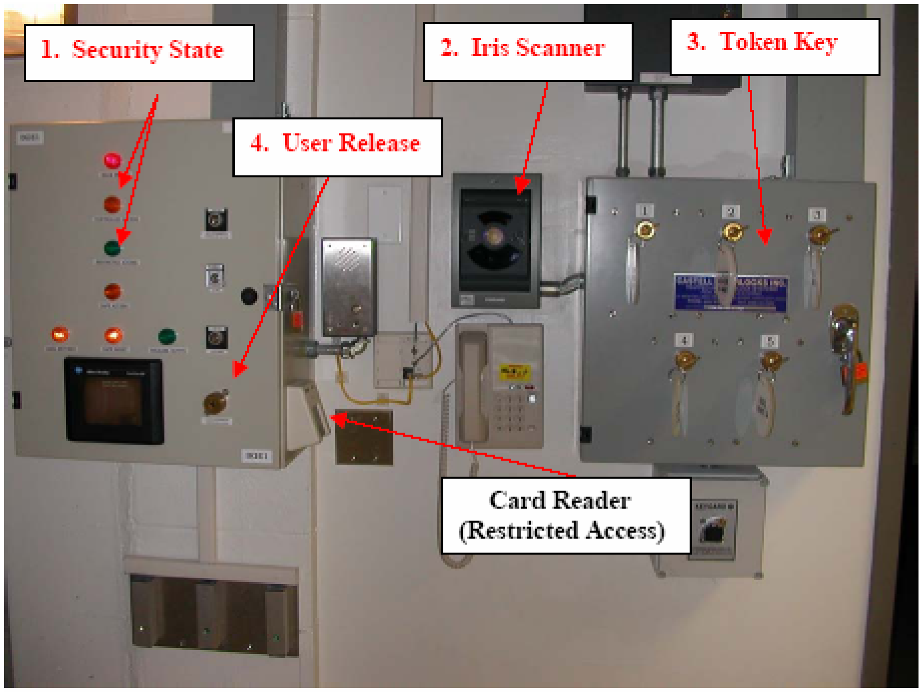


Figure 3.2.2.2.10.b Picture of NSRL Access Control System



3.2.3.Design Criteria and As-Built Characteristics for Fire Protection Systems

3.2.3.1.Design Criteria

The following presents the philosophy for the physical fire protection for the C-A Department. This philosophy establishes the methodology that was used in each Fire Hazard Analysis (FHA) for determining design requirements and choosing the most effective fire protection features.

The physical fire protection design meets the objectives of DOE Order 420.1, "Facility Safety." Implementation of the requirements follows the guidance provided in the

"Implementation Guide for use with DOE Orders 420.1 and 440.1, Fire Safety Program" (DOE Document G-420.1/B-0, G-440.1/E-0, dated September 30, 1995).

The primary means to document physical fire protection DOE 420.1 requirements are with Fire Hazards Analyses (FHA). The FHA identifies fire hazards and required physical fire protection that is incorporated into an evolving accelerator and experimental program in accordance with applicable DOE Orders, codes and standards. Key compliance documents include:

- the Standard Building Code (SBC), 1997 Edition
- National Fire Protection Association Codes and Standards
- BNL ESH Standard 4.0.0 Fire Safety Program, Rev. 0

If the listed codes and standards are silent on, or do not apply to a specific fire hazard, additional documents, such as Factory Mutual Data Sheets, are used based on direction from the BNL Fire Protection Engineer or designee. Any additional documents, and the reason for their use, are identified in the FHA.

The DOE Authority Having Jurisdiction (AHJ) must approve NFPA, SBC or SFPC deviations. The BNL Fire Protection Engineer or designee is responsible for acting as the interface between BNL and the DOE AHJ to obtain written approval of deviations from the DOE AHJ (DOE Order 420.1 Section 4.2.1.11 and DOE 440.1A, Attachment 1, Section 2.b.).

Each FHA was performed using the guidance provided in the "Implementation Guide for use with DOE Orders 420.1 and 440.1, Fire Safety Program" and all design related topical areas listed in this guideline were addressed. An FHA was performed for each significant facility to identify fire hazards and the acceptable level of physical protection (fire protection systems and building components) that are incorporated into the design. Recommendations are not made in the FHA itself, but are provided in a Design Review Record. The FHAs incorporate programmatic considerations. The FHAs were performed under the direction of a qualified fire protection engineer.

Required physical fire protection design features are identified in each FHA. In many cases, various means are available to meet the general criteria required by the DOE Order 420.1. The following guidelines were used in selecting the appropriate protection methods:

- wherever possible, passive protection methods are given preference over active systems
- fire rated or non-combustible construction, barriers and spatial separation are first reviewed for the ability to achieve the required level of protection before suppression systems are considered
- non-combustible materials are used wherever feasible to minimize the hazard
- active suppression systems are provided where required by the referenced documents
- wherever possible, wet pipe sprinklers are used, dry pipe for potentially freezing areas, and deluge for high challenge systems
- alarm and detection systems are provided where required by the referenced documents; type of detection is based on the type of fire expected, and the need for sensitivity or fast response, to provide for rapid manual response or effective process shutdown to minimize damage
- where building Maximum Possible Fire Loss (MPFL) values exceed \$50M, buildings are subdivided into fire areas with an MPFL value less than \$50M; where this approach is not operationally feasible, redundant fire protection systems are provided

- for facilities where DOE orders or referenced code requirements cannot be met, the need to develop an exemption or equivalency is identified

3.2.3.2.List of Fire Protection Codes, Standards and Design Guides

The following is a list of codes, standards and design guides that apply to Fire Protection. Any additional documents, and the reason for their use, are identified in the appropriate FHA. These codes, standards and design guides apply to facilities built in the last 10 years. Older facilities may comply with all or part of these standards.

- Americans with Disabilities Act of 1990, Public Law 101-336
- New York State Building Code, Latest Issue
- Occupational Safety & Health Act, 29 U.S.C.A. 651
- 29 C.F.R. 1910 - Occupational Safety & Health Standards
- DOE Order 440.1 - Worker Protection, Attachment 1, Section 5 (h)
- National Electric Safety Code
- ADA Accessibility Guidelines for Buildings and Facilities, January 1998
- Standard Fire Prevention Code (1997)
- NFPA 1 Fire Prevention Code (1997)
- NFPA 13 Installation of Sprinkler Systems (1996)
- NFPA 14 Installation of Standpipe and Hose Systems (1996)
- NFPA 17A Wet Chemical Extinguishing Systems (1998)
- NFPA 22 Water Tanks for Private Fire Protection (1998)

- NFPA 24 Private Fire Service Mains and their Appurtenances (1995)
- NFPA 30 Flammable and Combustible Liquids (1996)
- NFPA 45 Laboratories Using Chemicals (1996)
- NFPA 50A Gaseous Hydrogen Systems (1994)
- NFPA 50B Liquefied Hydrogen Systems (1994)
- NFPA 55 Compressed and Liquefied Gases in Portable Cylinders (1998)
- NFPA 70 National Electric Code (2002)
- NFPA 72 National Fire Alarm Code (1996)
- NFPA 75 Electronic Computer/Data Processing Equipment (1995)
- NFPA 80A Protection of Buildings from Exterior Fire Exposure (1996)
- NFPA 90A Standard for the Installation of Air Conditioning and Ventilating Systems (1996)
- NFPA 92A Smoke Control Systems (1996)
- NFPA 101 Life Safety Code (1997)
- NFPA 110 Emergency and Standby Power Systems (2002)
- NFPA 111 Stored Electrical Energy Emergency and Standby Power Systems (1996)
- NFPA 214 Water Cooling Towers (1996)
- NFPA 231C Rack Storage (1998)
- NFPA 299 Wildfires (1997)
- NFPA 318 Protection of Clean Rooms (1998)
- NFPA 750 Water Mist Protection Systems (1996)
- NFPA 780 Lighting Protection Systems (1997)
- NFPA 801 Facilities Handling Radioactive Materials (1998)

- NFPA 1141 Planned Building Groups (1998) [hydrant location only]
- DOE 420.1 Facility Safety
- DOE O 420.2 Safety Accelerator Facilities

3.2.3.3.As-Built Characteristics for Fire Protection Systems

The following fire-protection characteristics apply to all areas. As-built characteristics and/or design exceptions for specific areas are listed in Fire Hazard Assessments (FHAs) in appendices.

Brookhaven National Laboratory provides central fire-alarm station coverage by an Underwriter Laboratory listed multiplexed Site Fire Alarm System. The system complies with the requirements of NFPA 72 for a Style 7D System.

The system uses the existing site-telephone cable plant. RS232 signals are sent via full duplex line drivers. Each fire alarm panel has two channels connected to the Central Station. The panels are divided into 7 communication “loops.” The system can monitor more than 20,000 points. It is currently monitoring 3,800. Response time from alarm at the panel to alarm indication at the Central Station is less than 10 seconds, which is well within the 90 seconds allowed by NFPA 72.

The main console is at the Firehouse, Building 599. This station monitors all fire alarm signals, trouble and communication status alarms. A satellite station at Safeguards and Security, Building 50, receives only the fire alarm signals. If the Firehouse does not acknowledge an alarm within 90 seconds, the satellite station at Building 50 will receive an audible indication to handle the alarm. A second satellite station at AGS Main Control Room, Building 911, receives only the fire alarm signals from the RHIC/AGS accelerator buildings. A team of operators and Radiological Control Technicians respond during accelerator operating times. The ESH Coordinator, Collider Accelerator Support and Radiological Control Technicians respond during accelerator shutdown periods.

The following also apply to all fire detection/protection systems:

- when provided, fire detection is spaced at a maximum of 400 sq. ft. per detector
- alarm devices are supervised for circuit trouble and ground fault conditions by the facility's main fire alarm panel
- alarm and trouble signals report to the BNL Fire/Rescue Group via the Site Fire Alarm System
- water supply control valves to sprinkler systems are supervised by the Site Fire Alarm System
- manual fire alarm stations are provided at each exterior exit
- building occupants are alerted throughout the facility by combination fire alarm bells with integral strobe lights
- only Underwriter's Laboratory (UL) approved or listed equipment is used and it is used in the manner intended by the approval agency to ensure the most reliability

The following facilities have been reviewed for life safety and fire hazards. We note that DOE Order O440.1a, paragraph 4.2.1 indicates DOE contractors shall develop FHAs for all nuclear facilities, significant new facilities, and facilities that represent unique or significant fire safety risks. The list of C-AD facilities that meet that criterion is given in Table 3.2.3.3. The FHAs are posted at the C-AD web-site.

Table 3.2.3.3 List of Fire Hazards Analyses

Facility Description and Fire Hazard Analysis Link	Address	Year Built	Order of Preparation
Booster Applications Facility (NSRL)	Thomson Rd.	2002	1
Tandem Van De Graaff	59 Cornell Ave.	1968	2
Tandem to Booster Tunnel (TtB)	Grids 54,64,74,75	1985	3
200 MeV Linac	16 Fifth Avenue	1969	4
Booster Tunnel	Grid 54-64	1987	5
Siemens MG Power Supply	10 Cockcroft St.	1969	6
AGS RF Power Supply	12 Cockcroft St.	1969	7
C-AD Main Control Room and Westinghouse	35 Lawrence Dr.	1956	8
AGS Tunnel	35 Lawrence Dr.	1957	9
AGS Experimental Hall (Building 912) and BRAHMS and PHOBOS (Experiments at RHIC)	35 Lawrence Dr. and Ring Rd.	1958 and 1981/1994	10
Fast Extracted Beam Tunnels (U, V, W)	2 Thomson Rd.	1962	11
AGS to RHIC Transfer Line	Thomson Rd.	1971	12
RHIC Injection (W, X, and Y Lines) and Ring	Ring Rd.	1981	13
RHIC Cryogenic Control Room /Compressor Building	Ring Rd.	1981	14
RHIC RF Power Supply	Ring Rd.	1981	15
STAR Experiment	Ring Rd.	1981	16
PHENIX Experiment	Ring Rd.	1981	17
EBIS at Linac	16 Fifth Avenue	2006	18
RSVP Experiments (Building 912)	35 Lawrence Dr.	2006	19
eCooler	Ring Rd.	2007	20

3.2.4.Design Criteria and As-Built Characteristics for ODH Protection Systems

The Occupational Safety and Health Administration (OSHA) Respiratory Protection Standard (29CFR1910.134) defines an oxygen-deficient atmosphere as an atmosphere with an oxygen content below 19.5% by volume.

Collider-Accelerator staff is not exposed to an oxygen-deficient atmosphere under normal working conditions. If work needs to be performed in an oxygen-deficient atmosphere, specific work planning is conducted to ensure compliance with OSHA requirements. Persons exposed to reduced-oxygen atmospheres may experience adverse health consequences, including unconsciousness, or death.

On the other hand, events may occur such that an oxygen deficient environment is inadvertently created. Such events may occur in facilities that normally use significant amounts of gas such as helium, nitrogen or sulfur hexafloride. These include the Tandem van De Graaff accelerator rooms, an experimental area such as the g-2 muon storage ring, and many of the facilities at the RHIC. The methodology for assessing and classifying workplaces whereby abnormal conditions have the potential for producing an oxygen-deficient environment is given in BNL's SBMS.

Air normally contains about 21% oxygen with the remainder consisting mostly of nitrogen. Individuals exposed to reduced-oxygen atmospheres may suffer a variety of harmful effects. If exposure to reduced oxygen is terminated early enough, effects are generally reversible. If not, permanent central nervous system damage or lethality results. Major effects hindering escape from the vicinity of an oxygen deficiency are disorientation and unconsciousness. In addition, at facilities that use cryogenics, noise and cold are created in a leak event, and these hinder escape. If it is possible for C-A Department staff to be exposed to an atmosphere containing less than 19.5% oxygen following an accidental release of gas, then hazards are identified and control measures implemented to minimize the risk.

Depending on ODH Hazard Class, up to nine types of controls measures are used at C-A Department, see Table 3.2.4.a. ODH control measures may include warning signs, ventilation, medical approval as ODH-qualified, ODH training, personal oxygen monitor, self-rescue supplied atmosphere respirator, multiple personnel in communication, unexposed observer, and self-contained breathing apparatus. Warning signs and ventilation, controls listed as one and two in Table 3.2.4.a, are considered environmental controls. ODH signs are posted to warn potentially exposed individuals, and the minimum ventilation rate during occupancy is designed to be at least one volume change per hour, which may be accomplished by any reliable means. Higher-level controls, controls listed as three through nine, apply to individuals who have been classified as ODH-qualified. If individuals enter ODH Class 1 through ODH Class 4 areas unescorted, then they must have medical approval from the Occupational Medical Clinic (OMC).

For ODH Class 0 and greater, individuals receive training in oxygen deficiency hazards and safety measures associated with the operation. Retraining is required and training is the responsibility of the C-A Department. For ODH Class 1 and greater, the C-A Department also issues Personal Oxygen Monitors (POM). Each monitor has a unique identifying number and a sticker indicating the date due for calibration. The calibration frequency is every six months. The calibration sticker on the monitor is checked before use. Individuals also have ready access to Self-Rescue Supplied Atmosphere Respirators (SRSARs) during the work. Prior to working in an ODH Class 1 or greater area, personnel test the operation of their POM and verify the readiness of their SRSARs.

For ODH Class 2, more than one individual shall be present. For ODH Class 3 and greater, all personnel engaged in the operation are required to be in continuous communication with an observer who cannot be exposed to an oxygen deficiency. The purpose of the observer is to summon the Fire/Rescue Group in case of need. For ODH Class 4, individuals must wear a self-contained breathing apparatus (SCBA) during the operation. Prior designation as medically fit to wear an SCBA by the OMC is required before training in SCBA.

Table 3.2.4.a ODH Control Measures

ODH Hazard Class	0	1	2	3	4
Environmental Controls					
1. Warning signs	X	X	X	X	X
2. Ventilation			X	X	X
ODH-Qualified Personnel Controls					
3. Medical approval as ODH-qualified		X	X	X	X
4. ODH training	X	X	X	X	X
5. Personal oxygen monitor		X	X	X	X
6. Self-rescue supplied atmosphere respirator		X	X	X	
7. Multiple personnel in communication			X		
8. Unexposed observer				X	X
9. Self-contained breathing apparatus					X

X = Required

Specific areas at Collider-Accelerator facilities where controls for potential oxygen deficiency hazards (ODH) are implemented are listed in Table 3.2.4.b.

Table 3.2.4.b. Collider-Accelerator ODH Areas

ODH Area	ODH Class	Main Hazard
Collider Tunnel	0 (when gas < 50K)	Helium
Building 1002A	0 (when gas < 50K)	Helium
Building 1004B	0 (when gas < 50K)	Helium
Building 1006B	0 (when gas < 50K)	Helium and Nitrogen
Building 1008B	0 (when gas < 50K)	Helium
Building 1010A	0 (when gas < 50K)	Helium
Building 1012A	0 (when gas < 50K)	Helium
Building 1005R	0 (when gas < 50K) 1 (when liquid in pots)	Helium
Building 1005H	0 (main He storage or LN2 source not isolated and LOTO from building)	Helium
Building 1005E (west)	0 (main He storage or LN2 source not isolated and LOTO from building)	Helium and Nitrogen
Building 919 (g-2) 919 Compressor Room 919G Refrigerator Room 919 High Bay	 0 (when operating) 1 (when operating) 0 (when operating)	 Helium Helium Helium and Nitrogen
Tandem (901A) MP-6 and MP7 Pits Mechanical Equipment Rm. Electrical Equipment Rm. Building Equipment Rm.	 0 0 0 0	 Sulfur Hexafluoride Sulfur Hexafluoride Sulfur Hexafluoride Sulfur Hexafluoride

3.2.5. Design Criteria and As-Built Characteristics for Cryogenic Systems

3.2.5.1. Hydrogen Systems

The ion accelerators on occasion use fixed targets of up to 3 liters of liquid hydrogen. The cryogenic target enclosures are sufficient to contain and vent the hydrogen should target containment fail. Automatic fail-safe venting would occur should a fire break out near the target, should a power failure occur or should a leak develop at the target or target vacuum. Safety review of the design and a design analysis for hazards are performed for each target, before use. A cryogenic target watch is assigned round-the-clock during operations.

The refrigerated hydrogen/deuterium targets are normally located in Building 912. The targets are located in secondary beam lines typically upstream of spectrometer magnets. The support stands for targets generally allow them to move several feet out of the beam. Target controls, monitoring and hydrogen detection is located downstream typically at the downstream side of the dump shield for the secondary beam line. Dump shields for these beams are typically eight-foot high, four-foot thick concrete blocks.

Targets typically contain 2 to 3 liters of liquid hydrogen or 1 to 2 liters of liquid deuterium. The target vessels have upstream and downstream windows that are typically 6 inches in diameter and constructed of 0.006-inch thick aluminum epoxy laminated with typically 0.01-inch thick Kevlar mesh.

Targets are surrounded by Herculite and aluminum sheet metal enclosures with 6-mil Mylar windows for the experimental beam. The enclosure allows air to be drawn past the target equipment and vented into the low-pressure target vent system. The enclosure is designed to contain the hydrogen or deuterium in the event of a total failure of the target system. The electrical equipment inside enclosures meets Class I Division II standards in the National Electric Code for electrical circuits in explosive atmospheres.

3.2.5.2. Helium and Nitrogen Systems

3.2.5.2.1.General Design Criteria

The cryogenic systems are designed with due consideration to the inputs indicated in Table 3.2.5.2.1. Because of the nature of these systems, the mechanical design is most heavily influenced by the ASME Boiler and Pressure Vessel Code, Section VIII and the ASME Refinery Piping Code, B31.3-1990. Design, fabrication and testing were performed in accordance with these codes. Proprietary computer codes were used for stress calculations to aid design compliance with the codes. For example, engineering codes such as ANSYS®, LSDYNA-3D®, CODECALC® or COMPRESS®. These are pressure vessel analysis and design programs developed to evaluate pressure vessel components according to the current requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

All stress calculations have an independent engineering check.

Table 3.2.5.2.1 Application of Design Standards for Cryogenic Systems at RHIC

Application	Design Standards
Pressure Vessel Design, Fabrication and Testing	ASME Boiler and Pressure Vessel Code, Section VIII ANSI Standard B31.1, Power Piping ASME Chemical Plant and Petroleum Refinery Piping Code, B 31.3-1990
Welding Procedures	ASME Boiler and Pressure Vessel Code, Section IX
All Bellows and Expansion Joint Design	EJMA Code, Expansion Joint Manufacturers' Association
Gas and Liquid Storage Tank and Vessel Design and Relief Valve Design	CGA S-1.3-1980, Pressure Relief Device Standards, Part 3-Compressed Gas Storage Containers

Where vessels or pipes are operating at cryogenic temperatures, the material used is chosen to retain ductility at cryogenic temperatures. Cracks or other flaws that might somehow be initiated do not propagate to catastrophic size because of the material ductility, and because leaks significant enough to degrade insulating vacuum would increase the refrigerator heat load and result in an aborted run.

Complete and accurate Piping and Instrumentation Drawings (P&IDS) have been prepared for all cryogenic systems. The Collider-Accelerator Department maintains the files for the P&IDS. These records are changed only by means of Engineering Change Requests/Notices (ECR/ECN), which are part of the formal configuration-control process. No changes, except in emergencies, are made in the equipment and piping shown on these drawings until an ECR/ECN has been issued approving said change.

3.2.5.2.2.As-Built Characteristics for Cryogenic Systems

Refrigeration to provide 4-degree Kelvin supercritical helium gas required for RHIC is produced by the 25-kW helium refrigerator. The refrigerator is housed in two structures. The helium is distributed by means of piping and valve boxes, both of which are vacuum insulated, plus ancillary warm piping and valves. This piping system carries the helium to and from the main refrigerator passing out-of-doors, into the RHIC Tunnel, where it connects to the superconducting magnets, and into the six service buildings located near the six experimental areas around the RHIC Ring. An inventory of cryogenic gases, by location, is shown in Table 3.2.5.2.2.

The numbers in the last column in Table 3.2.5.2.2 reflect the maximum that any portion of the cryogenic system could hold while the cryogenic system is operating. That is, running the RHIC rings at maximum operating pressure, having full storage tanks, and having full pots in the refrigerator. These maximum numbers are not normal operations but could possibly be achieved. The C-A Department does not have enough helium gas on-hand for the entire RHIC cryogenic system to operate at these conditions simultaneously. Thus, the maximum numbers reflect the maximum that could be in any portion of the system (RHIC rings, tanks, etc.) at any one time.

Table 3.2.5.2.2 Helium Inventory and Location, Thousands of Cubic Feet

Volume of Vessel	Location	Inventory During Shutdown	Inventory Normal Operation	Inventory Maximum Operation
	OUT-OF-DOORS			
8	Compressor Buffer Tanks	8	18	150
160	RHIC Gas Storage Area	3100	600	2693
1	Outdoor VacJac Piping	1	452	543
4	30,000 gallon LHe Storage	2759	700	2759
	Total	5867	1770	6145
	COMPRESSOR BUILDING			
4	Compressor System	4	48	53
	Total	4	48	53
	CRYOGENIC BUILDING			
0.2	Cold Box #l	0.24	5	6
0.2	Cold Box #2	0.24	1	6
0.2	Cold Box #3	0.24	12	13
0.2	Cold Box #4	0.24	80	88
0.2	Cold Box #5	0.24	705	780
0.2	Other	0.24	75	28
	Total	1.44	878	921
	TUNNEL			
0.9	Sextant 1	1.0	540	650
0.9	Sextant 3	1.0	540	650
0.9	Sextant 5	1.0	540	650
0.9	Sextant 7	1.0	540	650
0.9	Sextant 9	1.0	540	650
0.9	Sextant 11	1.0	540	650
	Total	6.0	3240	3900
	SERVICE BUILDINGS			
1.7	2 o’clock	2	50	60
1.7	4 o’clock	2	50	60
1.7	6 o’clock	2	50	60
1.7	8 o’clock	2	50	60
1.7	10 o’clock	2	50	60
1.7	12 o’clock	2	50	60
	Total	12	300	360
	Grand Total	5890	6236	

The Cryogenic Building 1005R is a high bay, steel frame, masonry building of approximately 7,200 square feet, with a volume of about 240,000 cubic feet, and is located immediately west of, and contiguous to, the Collider Center, Building 1005S. Though contiguous, the two buildings are structurally separate to insure acceptable acoustic levels in the Collider Center. The Cryogenic Building includes an 18-foot by 50-foot truck service platform. Access is through a 12-foot roll-up door. The exterior of the building is comprised of concrete block with five, approximately 16 foot square, openings on the north side through which the Cold Boxes were installed. These openings were then sealed to the vacuum tanks of the Cold Boxes.

The Compressor Building 1005H is a one story, high bay, similar in construction to the Cryogenic Building. It is approximately 10,800 square feet in floor area with a volume of about 200,000 cubic feet. It houses the helium compressors and their associated equipment. It is located just to the northwest of the Cryogenic Building.

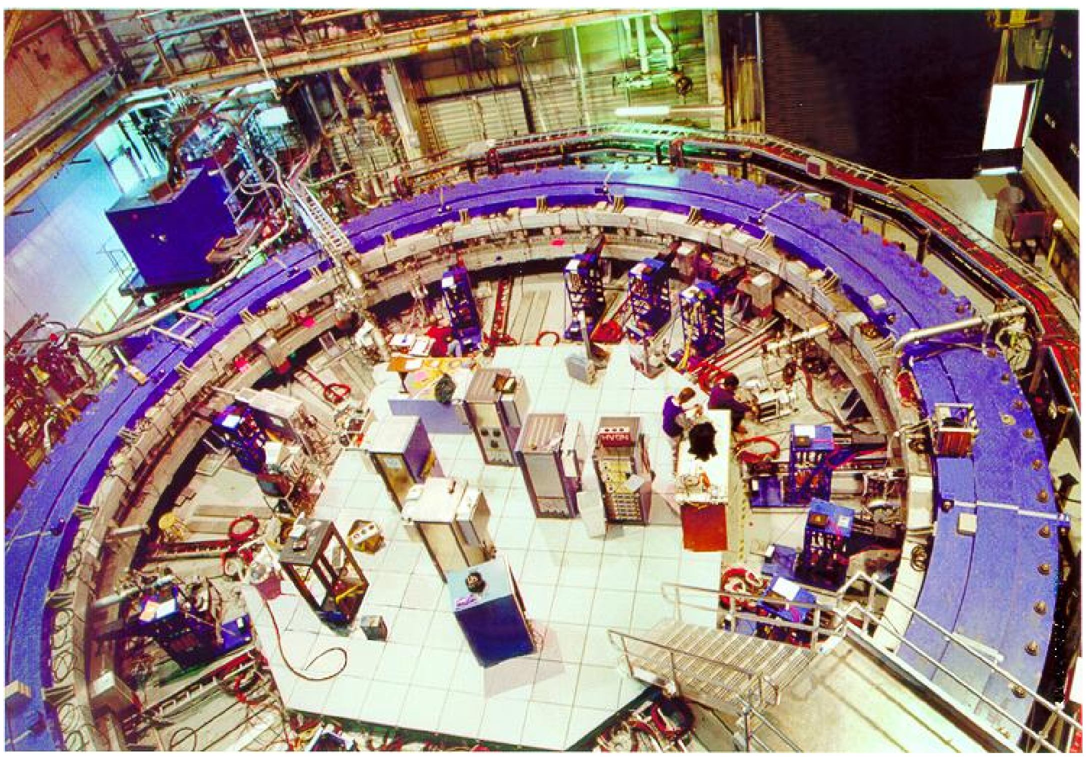
The six Service Buildings are metal frame, pre-engineered structures. The volume of these buildings varies from 75,000 to 113,000 cubic feet. Two Valve Boxes, one for each ring, are located in each Service Building. In addition, the Main Ring magnet power supplies are located in these buildings with their ancillary equipment. The six o'clock Service Building 1006B is also the location for a 700-W Helium Refrigerator, which typically operates only when the main 25 kW Helium Refrigerator is shutdown.

The Refrigerator and Compressor Buildings and the equipment located in them were reviewed by the BNL Cryogenic Safety Committee before the acceptance tests for the equipment were run. Approval for operation was received in 1984.

The Cryogenic Control Room is located in the Collider Center, Building 1005-S. A description of the control system may be found in the RHIC Design Manual.

The g-2 magnet in Building 919 is superconducting and requires liquid helium. The 1.451 T magnetic field of the magnet is used to constrain 3.094 GeV/c muons to move in a circle with a central orbit radius of 7.112 m. The muon storage region itself has a cross-sectional diameter of 9 cm. A photograph of the magnet is shown in Figure 3.2.5.2.2.

Figure 3.2.5.2.2 Picture of the g-2 Superconducting Magnet



The g-2 cryogenic system provides cooling for the g-2 superconducting magnets so that their operating temperature is less than the critical temperature of the superconductor with some safety margin.

The g-2 cryogenic system is divided into two parts. They are 1) the helium refrigerator and helium compressor system including the helium make up and recovery system, and 2) the control dewar and cryogenic distribution system for the g-2 storage ring superconducting magnet system. The two parts of the g-2 system are connected by low temperature supply and return lines that go to and from the refrigerator with 300 ^{o}K helium supply and return lines from the compressor system.

The cool down of 6200 kg of the g-2 solenoid cold mass and the cryogenic distribution system takes about three weeks. An additional 12 hours is required to fill the 1000 liter control dewar with the g-2 refrigerator running through the g-2 cryogenic system. Once the solenoids and the control dewar are at their normal operating temperature of 4.5 ^{o}K, the inflector is cooled to 4.5 ^{o}K in less than one hour.

Two-phase helium flow is supplied to the magnets by the helium refrigerator. Two-phase cooling avoids the increase in temperature along the flow circuit found in supercritical or single-phase gas cooling circuits. The operating temperature of the magnets is close to the temperature of the helium in the control dewar, which is about 0.3 ^{o}K difference. An advantage of two-phase helium cooling in tubes for the g-2 magnets is that the amount of helium in direct contact with the magnet coil is limited to the helium within the g-2 coil cooling tube. This has positive safety implications for the magnets and their cryogenic vacuum vessels.

The g-2 refrigeration system is self-regulating and it maintains a constant liquid level in the control dewar unless there is a gas loss from the system. By using this approach, the refrigeration delivered to the load is proportional to the heat load into the g-2 cryogenic system. The control dewar acts as a buffer vessel that can provide additional cooling by using the liquid stored in the dewar during times when the thermal load exceeds the capacity of the refrigerator. The major disadvantage of forced-flow two-phase helium cooling is that stopping flow will stop cooling. Therefore, when the refrigerator stops operating, the magnet warms up. The g-2 system uses a control dewar with 1000 liter storage capacity that can be fed into the cooling flow circuit to provide about 30 minutes continuous cooling before the magnet temperature rises above the critical temperature of the superconductor. This provides a redundant source of liquid helium when there is an electrical power failure or some other problem that can shut off the refrigerator. There is enough liquid stored in the control dewar to permit one to discharge the solenoids without quenching them.

The g-2 cryogenic control system is distributed among three locations, the magnet ring hall, the compressor room and the refrigerator room. Computers using a commercial software package communicate with programmable logic controllers. The system is responsible for monitoring and controlling temperature sensors, pressure transducers and valves. The cryogenic control software provides operator interface, real-time supervisory control and data acquisition and logging in both graphic and text formats.

3.2.6.Design Criteria and As-Built Characteristics of the TVDG Gas System

In any large high-voltage equipment, the presence of extremely high potential gradients necessitates the use of an insulating medium for stable operation. For this reason, the high voltage structures of MP6 and MP7 are enclosed within large pressure vessels pressurized with insulating gas. These vessels are code stamped, meeting the ASME Boiler and Pressure Vessel Code, Section VIII, Division I, with a maximum rated pressure of 300 psig. Overpressure relief valves rated at 250 psig are located on the main fill line and on each vessel.

Each of the Tandem Van de Graaff accelerators, MP6 are MP7, are located in Building 901A. Each accelerator pressure vessel (11,250 ft^3) contains an insulating gas mixture at a nominal operating pressure of about 12 atmospheres. The gas mixture is composed of roughly 45% SF, 45% N_2, 5% CO_2 and 5% O. The gas mixture is not routinely released. The gas is scavenged down to a pressure of 1000 micron (1 torr) before backfilling the vessel with air to allow for personnel entry.

The Insulating Gas Storage Facility is located atop the hill, which rises north from the Building 901A roof and crests at Building 704. The structure is completely separate from the 901A structure. It consists of two opposing banks of high-pressure gas storage cylinders with an intervening concrete structure allowing access to the gas system. Each bank consists of three buried layers of cylinders separated by earth, with the upper layer 42 inches below grade.

The gas handling system is capable of moving large amounts of insulating gas safely and quickly between the accelerator pressure vessels and the insulating gas storage facility. In order to permit opening and closing of an accelerator pressure vessel in a single shift, the system can handle all phases of gas pumping in four hours. To avoid temperature shocking the glass and metal accelerator tubes and column structures within the pressure vessels the maximum rate of temperature change is 10 ^{o}F/hr, with a maximum gradient along the accelerator structures of 10°F. To this end, one external and two internal heat exchangers for each accelerator provide heating or cooling to the insulating gas as necessary. Automatic temperature controllers are used to modulate hot and cold-water flow to these heat exchangers. Based on tests, the low thermal conductivity and high heat capacity of these structures are enough to maintain temperatures within the temperature specifications. Therefore, the use of the temperature regulating system is standard procedure, and is not a requirement for safety.

The two major considerations for personnel safety are the physical hazards associated with a rupture of a system component due to over-pressure, and the oxygen-deficiency hazard (ODH) posed by the insulating gas. To minimize these hazards, the gas handling system includes a variety of safety features. These include: 1) written procedures for all phases of gas transferals, 2) automatic pressure control, 3) flow-control valves at key points, 4) the use of over-pressure relief devices throughout the system, 4) keyed locks and micro-switches to ensure that a vessel is secured prior to pressurization and 6) ODH monitoring and alarms.

The relief valves are tested every five years. All accelerator-room relief valves discharge to their immediate locale. Mechanical-equipment-room relief valves vent external to the building in order to eliminate areas at TVDG that have a potential to be greater than ODH Class 1. Automatic isolation ball valves and overpressure relief flanges are located at beam-line and accelerator penetrations to halt gas flow in the event of an accelerator tube rupture. The valves actuate upon loss of vacuum in the accelerator tubes. Overpressure relief flanges prevent pressurization of the beam-lines while the ball valves are closing.

To alert personnel of an oxygen displacement hazard, fixed oxygen sensing and insulating gas detection equipment constantly monitor ambient conditions. In particular, an SF, detection system monitors the gas storage facility and various locations in the Accelerator Rooms with sensitivity adjustable down to 10 ppm. Oxygen monitors on both the main level and the pit level of the Accelerator Rooms and in the Mechanical Equipment Room alarm below 19.5%. Should any unusual levels of oxygen or SF_6, be detected, these systems will alert operations personnel immediately. An operator can then initiate emergency procedures in the OPM.

If the SF_6 alarm activates, then the situation is likely to be a minor gas leak, a maintenance problem rather than an emergency. After checking to ensure that there is no indication of oxygen deficiency, operators enter the affected area. As a precaution, they carry portable oxygen and halogen monitors and two-way radios while locating and isolating the leak. If a single oxygen-monitor alarms, with no other evidence of a gas leak, it is likely that the monitor is giving a false alarm and requires service. After activating a high-speed purge-ventilation-system and notifying the Local Emergency Coordinator, operators may enter the affected area, carrying the same safety equipment as for an SF, alarm. In each of the above cases, emergency responses are initiated if portable monitors indicate an oxygen deficiency.

If an oxygen monitor alarms along with an SF_6 monitor alarm, or an audible leak is heard or a second oxygen monitor alarms, then the situation is treated as an emergency and Laboratory Emergency Response personnel are notified immediately. The high-speed purge-ventilation is initiated and the Local Emergency Coordinator is notified. TVDG operators make an announcement over the PA system, and alert the MCR, and Plant Engineering that a dangerous asphyxiating condition may exist. Plant Engineering is notified due to possible accumulation of asphyxiating gas in the manholes in the area.

During the emergency, the building is evacuated. It is unlikely that individuals outside of the immediate area are at risk of asphyxiation. The building ventilation system does not circulate air from the Accelerator Rooms into the office and laboratory areas. Although there are some connections to low lying areas of the building via cable tray passageways and under doorways, it is expected that normal building ventilation combined with mixing with room air would prevent concentrations from reaching hazardous levels. The primary purpose of the building evacuation is to ensure that individuals do not enter affected areas and to avoid interference with emergency responders.

In certain applications, it has been shown that SF_6 can decompose in an electric discharge, producing toxic reactive compounds such as S_2F_{10}. There is no evidence that these compounds have been detected in harmful concentrations in the insulating gas of an accelerator. The activated alumina drying towers through which the insulating gas of the TVDG accelerators constantly circulates form effective scrubbers for these compounds. Independent documented toxicity tests of the gas mixture from the TVDG vessels have shown no evidence of toxicity.

3.2.7. Design Criteria and As-Built Characteristics of Shielding

3.2.7.1. Shielding Policy

The main features of this shielding policy are currently delineated in the Collider-Accelerator Department Operations Procedure Manual.[8, 9] The principal components of this

[8] http://www.agsrhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-12.PDF Procedure for Review of Collider-Accelerator Department Shielding Design

[9] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch08/08-13.PDF Collider-Accelerator Department Procedure for Shielding/Barrier Removal, Removal of Primary Area Beam Line Components, or Modifications

policy are reviewed here for completeness. The shielding policy is also summarized in Appendix 3 for easy reference.

The primary purpose of the shielding policy is to assure that all radiation related requirements and administrative control levels are satisfied. Specifically, the Collider-Accelerator Department's Radiation Safety Committee reviews facility-shielding configurations to assure:

- annual site-boundary dose equivalent is less than 5 mrem
- annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities is less than 25 mrem
- maximum dose equivalent to any area where access is not controlled is limited to less than 20 mrem during a fault condition[10]
- for continuously occupied locations, the dose equivalent rate is ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week
- dose equivalent rates where occupancy is not continuous is ALARA, but in no case exceeds 1 rem in one year for whole body radiation, or 3 rem in one year for the lens of the eye, or 10 rem in one year for any organ

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration.

[10] During operation, the RHIC berm is a Controlled Area. However, the access road into RHIC is uncontrolled. The short uncontrolled portion of road atop the berm is protected by Chipmunk radiation monitors. This area is the single exception to the C-AD shielding policy for protection against faults, and maximum fault dose on the roadway is estimated to be less than 50 mrem if a highly unlikely point loss occurs at that location.

Radiation surveys and fault studies are conducted to verify the adequacy of any new or modified shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed by additional Collider-Accelerator Department procedures, which are not elaborated here.[11]

Any modifications to shielding configurations are likewise closely proscribed. Each Department accelerator or experimental area is assigned a liaison physicist and liaison engineer. The liaison physicist is responsible, in consultation with the Radiation Safety Committee (RSC) where appropriate, for determining safe conditions for any shielding modifications. The liaison engineer is responsible for ensuring that the safe conditions are met, for effecting any modification, and for notifying other responsible Collider-Accelerator Department personnel, including the Operations Coordinator, as well as experimenters both prior to and on completion of the modifications. Additional procedures exist to ensure that policy with respect to control of radioactive shielding is implemented, which are not elaborated here.

During the review, the RSC examines the layout of the facility, experimental area and/or the beam transport system. Possible radiation sources during fault conditions are examined. These possible sources include apertures, collimators, instrumentation, valves, magnets, targets, detectors and beam scraping in the beam transport pipe. Sources caused by improperly adjusted beam elements are also considered. Based on shielding and experimental requirements, the RSC then sets the normal operating parameters for the area into the Committee records. For example, the RSC can approve primary beam energy, particles per second on target and the target parameters such as beam spot size. The RSC also establishes the radiological classification of

[11] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-01-09.PDF Fault Study Procedure for Primary and Secondary Areas

areas outside of shielded areas that have dose rates above background; that is, they review and approve contiguous Radiation Areas and High Radiation Areas that result from beam operations. Area classifications are established for both normal and abnormal operating conditions.

3.2.7.2.Fault Studies

RSC representatives, liaison physicists and MCR operations staff perform fault studies in primary and secondary beam areas in order to verify the adequacy of shielding and radiological controls following a shielding modification. An RSC member or other knowledgeable person, e.g. liaison physicist, is assigned by the RSC to lead the fault study. Because the study may produce greater than routine levels of radiation, it often involves changing the state of a chipmunk radiation monitor from interlock to non-interlock mode via a local switch setting on the unit. This change requires RSC review and equivalent administrative controls must be in place until the study is over and the state of the radiation monitor is returned to normal.

At the start of study, a specific Fault Study Plan must be defined by the knowledgeable person specifically for the beam properties in the area. This plan must be reviewed and approved by the RSC. The end of study is part of the plan and occurs when the operators return to routine operating mode for the accelerator. Only qualified RCTs assist with the pulsed radiation surveys during the fault study.

Beam fault studies are conducted using the minimum beam intensity necessary to complete the study efficiently and they are consistent with ALARA practices. Any fault study requiring higher intensity than 10% of normal operating intensity must be reviewed and approved by the RSC. Beam not lost at the intended location(s) for the fault study is safely aborted, if practicable, at target stations, beam dumps or other acceptable locations. Area announcements over the PA are made before initiating the fault condition, and at the time that the fault study is completed. The beam is "ON" in the fault condition only as long as necessary for adequate survey measurements to be taken.

The survey team is informed of the expected exposures during the study based on the dose rate estimates provided in the Fault Study Plan. The survey team determines whether it is appropriate to participate based on their accumulated dose, and the dose estimates are used in the Radiation Work Permit issued for the study.

Before the fault conditions can be established, the appropriate locations for the desired fault study are swept. The vicinity of the fault study, including nearby potential beam loss locations, is posted by RCTs with signs and tape where appropriate.

Data for the fault study are entered in a designated fault study logbook for the area. Data includes location of loss, beam intensity and measured radiation levels. The RSC Chair must review the fault study results within a reasonable period to determine if changes to the shielding and/or area access requirements are necessary. That is, the RSC Chair must concur or disagree with the classification of the area indicated in Table 3.2.2.1 based on the results of the fault study.

3.2.7.3.Configuration Control of Shielding Drawings

The C-A Department RSC Chair and the C-A Department ESHQ Associate Chair must approve the shielding design. The record of approval can be part of RSC meeting minutes or a separate document signed by the RSC Chair and the ESHQ Associate Chair. The official shielding print is approved and assigned an identifying number in order to become a permanent record. The C-A RSC Chair files the minutes of the Committee review of the shielding design and approval, and provides the project engineer with a copy of the approval. Preparation, modification and issuance of engineering drawings are done in accordance with quality assurance procedures in OPM Chapter 13.[12]

3.2.7.4.Typical Earth Berm Shield

Figures 3.2.7.4.a and 3.2.7.4.b show typical earth berms used for shielding. These particular berms are for the Booster beam dump and the NSRL line (R line). The Booster beam dump also has a cap, which is seen in the picture. The photo of the new R-line berm (Figure 3.2.7.4.b) also shows the standard geo-membrane-type cap typically used for groundwater protection. Also visible are the ventilation shafts in the R-line berm. Since 2002, geo-membrane caps have been placed over new shield berms as they are constructed. More information on berm caps and the reasons for their use is provided in Section 3.2.7.7. An addition layer of soil is placed over the membrane to complete the berm. Earth berm shields and their caps are covered with grass to prevent erosion. Berm shields are inspected at the start-up and conclusion of each running period, which is typically twice per year. Soil erosion, tree or shrub penetration and cap integrity, where applicable, are the main reasons for inspections.

[12] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual

Figure 3.2.7.4.a Typical Earth Berm and Cap Used for Shielding, Booster Beam Dump

Figure 3.2.7.4.b Typical Earth Berm and Cap Used for Shielding, R Line (NSRL)

Figure 3.2.7.4.c shows the earth berm for the U line. Currently, there is no cap for the earth shield at the U line; however, experiments are restricted to low intensity and minimal beam losses such that rainwater leachate containing soil-activation products such as tritium will never exceed the Drinking Water Standard. Future experiments to be built in this area will require the addition of a soil cap. On the other hand, if rainwater percolates through the soil over the U line tunnel, then it would ultimately drain onto the supporting concrete pad and would join many thousands of gallons of storm water run-off entering the on-site recharge basin via the trench

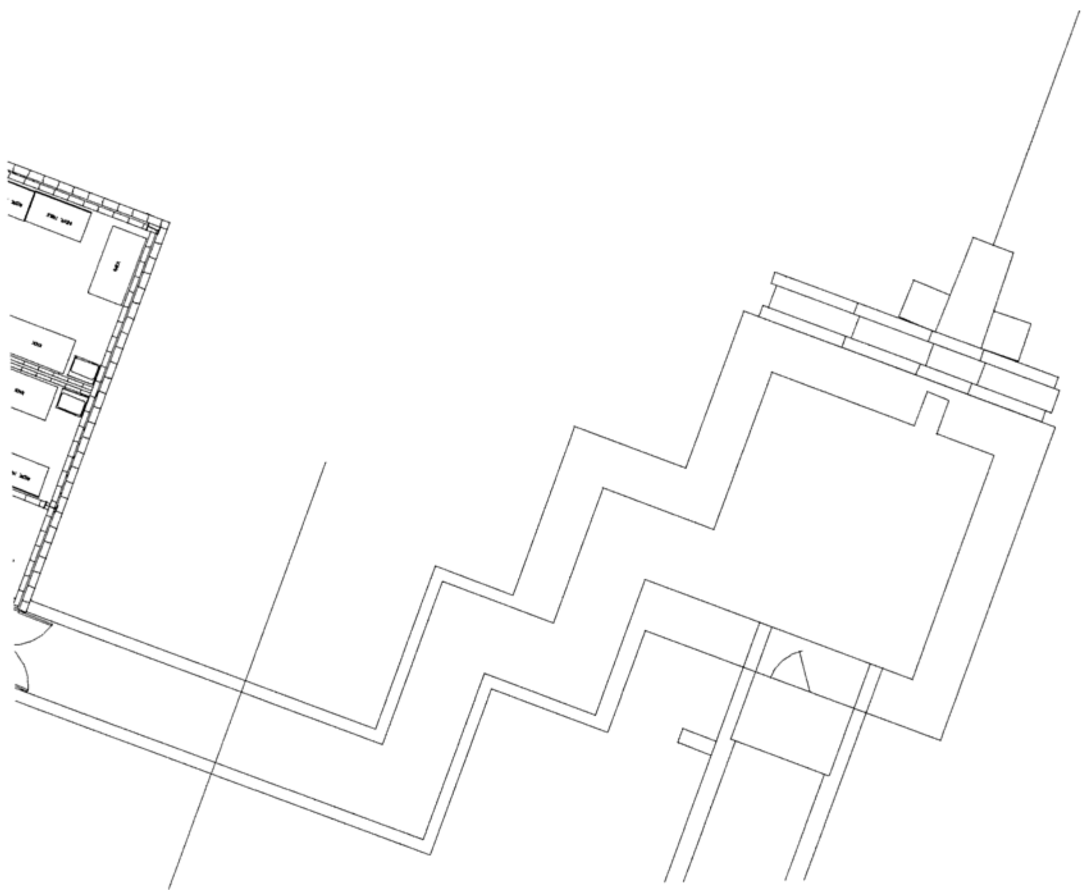
network in the apron, which is also visible in the photo of the U line. This runoff is routinely monitored for tritium concentrations at the recharge basin and discharges are at or near naturally occurring concentrations.

Figure 3.2.7.4.c Typical Earth Berm Used for Shielding, U Line

3.2.7.5.Typical Labyrinth Design

Figure 3.2.7.5 shows a typical labyrinth design. Multi-leg labyrinths are used to minimize routine radiation levels. Dose calculations for labyrinths are generally simulated by using the MCNPX code. The dose due to neutrons of energy less than 20 MeV is often calculated, since this is very nearly all the dose at the closest people should be when the beam is on at high-energy accelerators.

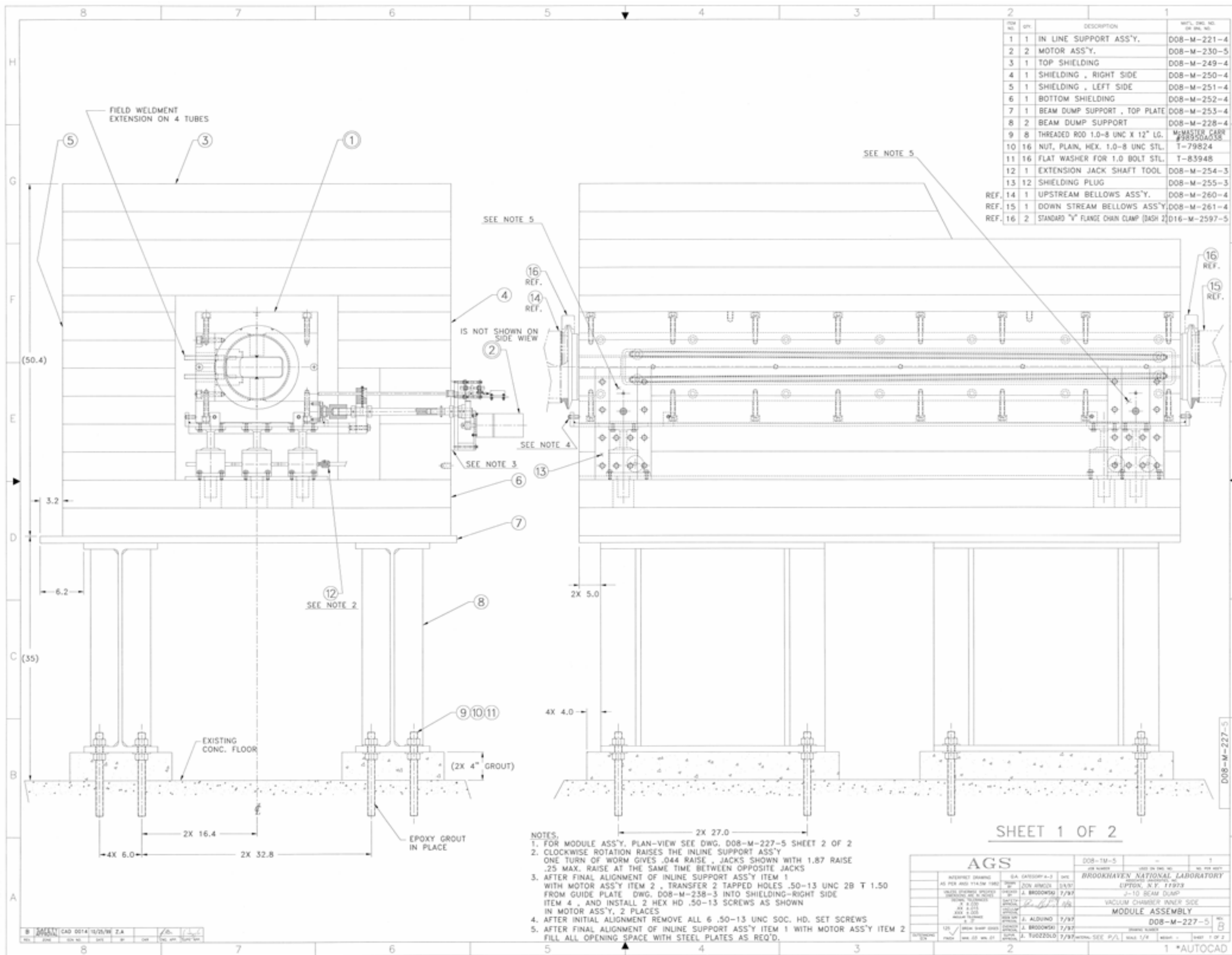
Figure 3.2.7.5 Typical Labyrinth Design



3.2.7.6.Typical Shielding for an Accelerator Collimator and Dump/Scraper

The J10 scraper in the AGS Ring is typical of a beam scraper in an accelerator (See Figure 3.2.7.6). It is designed to have 2 feet of iron around the beam impact point with in general 12 feet of drift space to the tunnel wall, which is on average 1-foot thick concrete. Typically, 24 GeV beam and 5% of the annual average beam intensity winds up in the scraper. The iron around the scraper minimizes the amount of secondary particles that escape into the soil shielding. In the case of the J10 scraper, 3 to 5 feet of concrete are buried in the soil berm around the scraper, which greatly reduces soil activation.

Figure 3.2.7.6 Drawing of J-10 Dump in AGS Showing Iron Shielding



3.2.7.7. Caps over Activated Soil Locations

When a high-energy particle interacts with matter, many secondary particles are emitted which could themselves have a high enough energy to produce additional particles when they interact, thus creating a nuclear particle cascade. Most high-energy secondary particles interact in the shielding around the targets. The materials used in the construction of the target areas are limited in number, the most important being iron, steel, copper, aluminum, concrete and earth. When a high-energy secondary particle, which is usually a neutron with energy between 20 MeV and 100 GeV, interacts in these materials, a variety of radioactive atoms is produced. The mass numbers of the radioactive atoms range from the mass number of the target-atom-plus-the-particle down to a mass number of three, which is tritium the radioactive atom with the smallest mass. Most of the radioactive atoms are very short-lived and decay back to stable atoms quickly. It is important to recognize that most of these manufactured radioactive atoms are deeply entrained in magnets and in concrete shielding. This is due to the penetrating ability of the high-energy secondary particles. These entrained radioactive atoms are not readily dispersible, even in a fire.

Some secondary radiation from proton interactions can penetrate the iron and concrete shielding around a target hall and interact with the nuclei of Si and O atoms present in nearby soil. The two most important long-lived radioactive species created by secondary radiation interactions in soil are 12.3-year ^{3}H, and 2.6-year ^{22}Na. Other short-lived radioactive atoms are produced but they decay quickly to stable atoms. If rainwater is allowed to infiltrate the activated soil shielding, the long-lived radioactive atoms can be leached from the soils and carried downward to the ground water. To prevent this leaching process, the soil shielding is capped by a water impermeable barrier. It is noted that all planned beam-loss areas such as beam dumps, beam stops and target caves at the C-A Department accelerators and experimental areas are protected from rainwater by roofs, concrete caps or geo-membrane caps. The caps are designed to meet requirements in SBMS, Design Practice for Known Beam-Loss Locations.

In accelerators, most shielding is ordinary earth and concrete. Iron is often used as beam-stop wherever space is at a premium. Because iron is denser than earth or concrete, iron greatly decreases the size of a beam dump. In one area, the C line, depleted uranium blocks were used in part of the beam dump. The use of uranium saved volume where space was limited. The uranium beam dump effectively absorbs muon radiation, which allows the beam dump to be shorter in length. However, uranium presents other hazards and a separate safety analysis was performed for this shielding application.[13] Subject to funding, these uranium shield blocks are scheduled to be removed and appropriately dispositioned in FY05.

A beam dump serves as the preferred repository for any beam that might be lost in the accelerators before reaching the experimental areas. Ideally, all residual radiation would be in the dump rather than being spread around other accelerator components. A beam dump in an accelerator is a solid block of metal, usually several feet thick. In Booster and AGS, the dump encircles the beam and has a opening through it to allow beam to pass through (see Figure 3.7.2.6). The upstream end of the dump has a protruding lip on the inside, which is used to "scrape" the beam, removing the outermost particles from the beam orbit. At RHIC, a fast-kicker magnet is used to kick the whole beam onto the face of the dump to give high efficiency

[13] Implementation Plan and Basis for Interim Operation with Preliminary Hazard Assessment for AGS Uranium Shield Block and Experiment 877 Uranium Calorimeters, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York 11973, August 3, 1993.

absorption of beam when required. The beam dump at RHIC is to the side of the circulating beam rather than encircling the beam; however, collimators, which encircle the beam, are used at separate locations to remove any halo of particles.

There are no beam dumps in the Linac, only beam stops. Typically, thick HDPE liners cover stops, dumps and collimators in order to shed rainwater away from potentially activated sections of soil shielding. The activated soil is predominantly forward of the absorber block or collimator due to the forward momentum of the secondary particles. A typical HDPE liner is shown in Figure 3.2.7.4.b.

The large angle of the Booster berm prevented the use of standard geo-membrane-type materials for groundwater protection at this location (see Figure 3.2.7.4.a). Therefore, a Gunite cap was installed and extends over an area of about 3000 ft^2 and is about 5-inches thick. Gunite is the best material for the cap because of ease of installation and high strength. Gunite strength approaches 5000 psi, which is characteristic of reinforced concrete. As an added feature, the Gunite was capped by EDPM rubber, which is standard roofing membrane. To ensure continued integrity of the Gunite, it is be inspected by the responsible C-AD Liaison Engineer every year.

Target caves house and shield the primary production targets in the fixed target experimental areas. Secondary particles, which are the focus of most experiments, are produced through interactions of the primary protons in target material. Targets are frequently made of metal by virtue of their refractory characteristics, thermal conductivity and high mass-density. A typical target is several hundred grams of platinum. About half the primary beam interacts in a target and virtually all the secondary particles produced in the target leave the target and interact elsewhere.

The target cave is the terminus of the primary beam transport for fixed target experiments. Beam is transported through a series of magnets providing control of the size of the beam and the beam direction. Beam interactions remote from the production target are minimized by confining the beam to a pipe evacuated of air. This beam pipe runs the entire length of the accelerator complex, through magnets and beam-line equipment. There are over six miles of evacuated beam pipe in use at the complex.

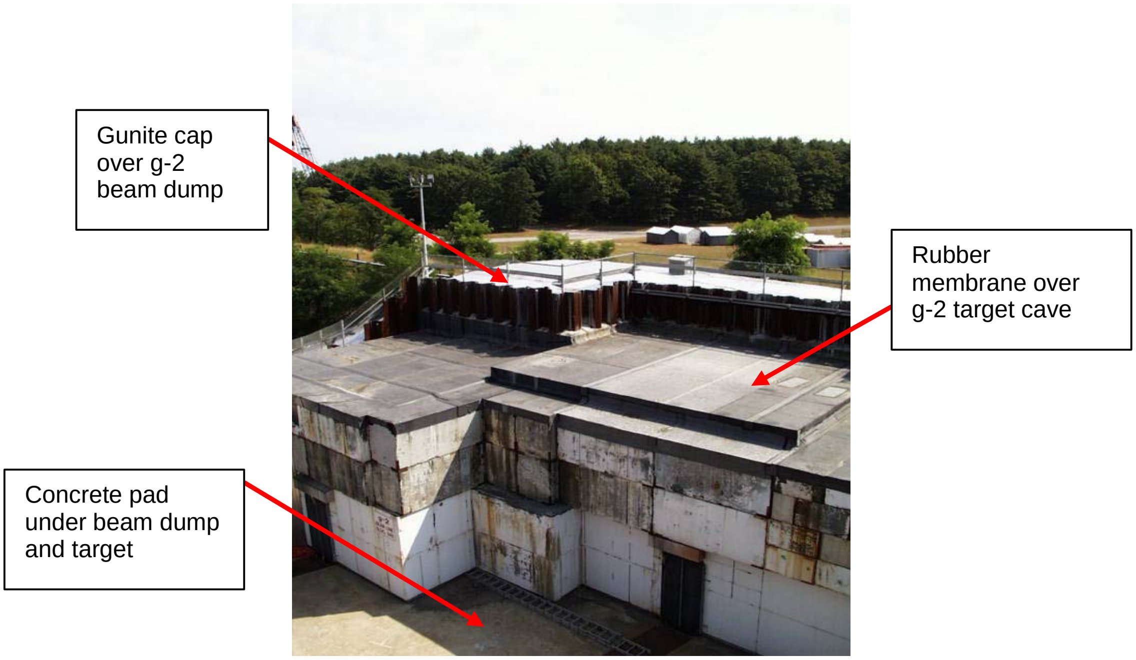
Target caves are constructed of heavy concrete and steel shielding and they have labyrinthine entry passages in order to prevent personnel exposure. The walls and floor of a target cave retain most of the radioactive atoms that are created by secondary particles emanating +from a target.

Figures 3.2.7.7.a, b and c show the roofed structures over the target caves. These roof structures are designed to shed rainwater to the paved areas that surround the experimental areas. This rainwater from the roofs flows directly to storm sewers and if shed to paved areas, to storm sewers located in paved areas and then into the recharge basin known as HN.

Figure 3.2.7.7.a Roof and Concrete Floor over Activated Soil Areas at Building 912

Figure 3.2.7.7.b Roof and Paved Area over Activated Soil Areas at Building 912

Figure 3.2.7.7.c Rubber Roof, Gunite and Paved Areas over Activated Soil Areas at g-2



Figures 3.2.7.7.d and e show the geo-membrane structures over potentially activated soil areas. These geo-membrane structures are designed to shed rainwater to the unaffected soil that surrounds the experimental areas.

Figure 3.2.7.7.d Geo-membrane Over Potentially Activated Soil Areas at NSRL

Figure 3.2.7.7.e Geo-membrane Over Potentially Activated Soil Areas at RHIC

Primary and secondary beam dumps are the sinks used to absorb the energy and concomitant radiation from beams that have completed their utility. The length and transverse dimensions of the dump are designed to assure that the radiation generated from a primary beam of 30-GeV protons is sufficiently attenuated. The iron beam dump for the g-2 experiment, for example, is 50 x 10 x 10 feet, and it sits on a 3-foot thick concrete pad. We note that the size of beam dumps is such that they entrain the bulk of radioactive atoms created because of stopping primary particles and most of their secondaries. A cap over a primary beam dump is required if significant secondary radiation reaches soil to create activation. The threshold for a cap is any potential to exceed 5% of the Drinking Water Standard in rainwater leachate that goes to groundwater. See Figure 3.2.7.7.c for an example of a cap over the external g-2 beam dump.

3.2.7.7.1. Activated Soil Locations

The Linac injects protons into the Booster Ring and into the Brookhaven Linac Isotopes Producer (BLIP). The BLIP is under the purview of the BNL Medical Department and soil activation for the BLIP facility is estimated in Reference 14.

Detailed computation of total soil radioactivity near beam stops, beam dumps and targets is difficult. Calculations and soil measurements are on going and the Collider-Accelerator Department is developing a detailed archive of information that will document the size and shape of all soil activation areas. The archive project is anticipated to be complete in 2005 (see Table 3.2.7.7.1). Note the Table refers to Fact Sheets and Map References that will be developed as part of the project.

[14] "Soil Activation Computation for BLIP," BNL Memorandum, J. Alessi, E. Lessard, and L. Mausner, to P. Paul, AGS Department, Brookhaven National Laboratory, Upton, New York 11973, May 7, 1998.

Table 3.2.7.7.1 Potential Activated Soil Shielding Areas at Accelerator Facilities Prioritization of Fact Sheet Development

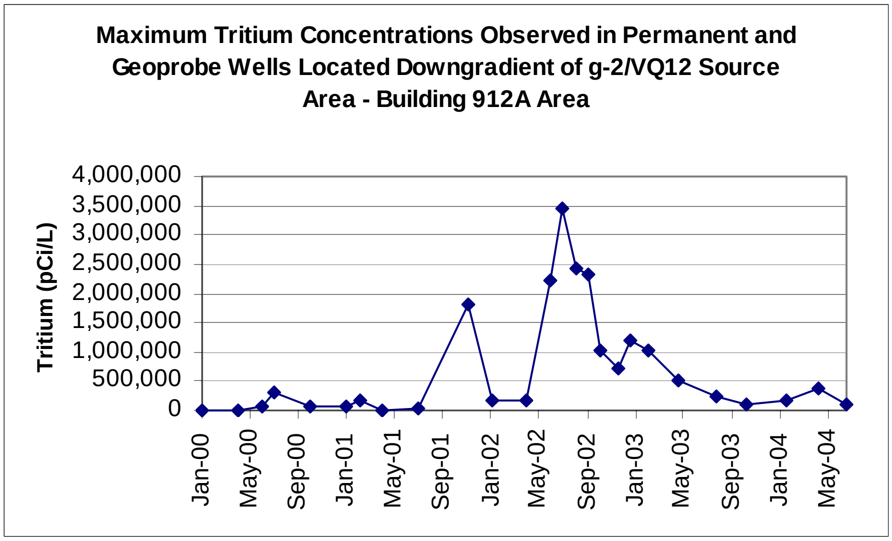
Fact Sheet	Activation Area	Responsible Department	Map Reference
1	g-2 VQ-12 source area	C-AD	22
2	g-2 V-line target	C-AD	20
3	g-2 V-line dump	C-AD	21
4	Building 912 – A target	C-AD	8
5	Building 912 – A dump	C-AD	9
6	Building 912 – B target	C-AD	10
7	Building 912 – B5 target	C-AD	11
8	Building 912 – B dump	C-AD	12
9	Building 912 – C target	C-AD	13
10	Building 912 – C3 target	C-AD	14
11	Building 912 – C1-C3 split	C-AD	15
12	Building 912 – C3C1, C1Q4	C-AD	16
13	Building 912 – C dump	C-AD	17
14	Building 912 – D target	C-AD	18
15	Building 912 – D dump	C-AD	19
16	AGS Ring – A10 fast beam	C-AD	25
17	AGS Ring – A20 200 MeV inflector	C-AD	26
18	AGS Ring – B10; near old HITL-2 house	C-AD	27
19	AGS Ring – F5 septum	C-AD	28
20	AGS Ring – F10 septum	C-AD	29
21	AGS Ring – F20 internal targets	C-AD	30
22	AGS Ring – G10 internal target	C-AD	48
23	AGS Ring – I10 area	C-AD	31
24	AGS Ring - I13 internal target	C-AD	49
25	AGS Ring – L20 injection (old and new)	C-AD	32
26	AGS Ring – Former H Area	C-AD	33
27	AGS Ring – Former E20 catcher	C-AD	34
28	AGS Ring – J10 catcher	C-AD	35
29	AGS Booster – old dump	C-AD	36
30	AGS Booster – new dump	C-AD	37
31	BTA Extraction (Building 914)	C-AD	45
32	BLIP target	Medical	38
33	BLIP spur	C-AD	39
34	LINAC Stop A	C-AD	40
35	LINAC Stop B	C-AD	41
36	LINAC Stop C	C-AD	42
37	LINAC to Booster transition (EBIS)	C-AD	43
38	HEBT stop	C-AD	44
39	Building 927 – Former U-line target	C-AD	23
40	Building 927 – Former U-line dump	C-AD	24
41	RHIC Y dump	C-AD	1
42	RHIC Blue-line dump	C-AD	2
43	RHIC Yellow-line dump	C-AD	3
44	RHIC Blue-line collimators – Sector 8	C-AD	4
45	RHIC Yellow-line collimators – Sector 7	C-AD	5
46	NSRL target	C-AD	6
47	NSRL dump	C-AD	7
48	Building 937 - Rad Effects Facility	EENS	46
49	Building 939 – NBTF	EENS	47

As an example of the Fact Sheets under development, a brief set of facts is listed here for the g-2 area; specifically, for the area near the VQ-12 magnet, which is a quadrupole magnet just before the V target in the fast beam experimental area.

The VQ-12 magnet was struck by significant amounts of proton beam for several years in the late 1990s. This beam loss was not anticipated and C-AD has subsequently taken measures to prevent unintended beam losses in the future. The secondary radiation from proton interactions on the magnet iron penetrated the minimal amount of concrete shielding surrounding the VQ-12 magnet and interacted with the nuclei of Si and O atoms present in nearby soil. The two most important long-lived radioactive species created by secondary radiation interactions in soil at the VQ-12 area were 12.3-year ^{3}H, and 2.6-year ^{22}Na. Initially the VQ-12 area was not capped, rainwater infiltrated the activated soil shielding, and tritium atoms leached from the soils and were carried downward to the ground water. To prevent this leaching process, the soil shielding was capped by a water impermeable barrier in December 1999.

Figure 3.2.7.7.1.a shows the tritium concentrations in groundwater that were created from this event. This tritium plume is monitored and will be monitored for the next 20 to 25 years, or until the tritium concentrations dissipate below levels of concern. Studies and calculations show the plume is very narrow and cigar shaped, and it not expected to cause tritium concentrations above the Drinking Water Standard in offsite or onsite supply wells.

Figure 3.2.7.7.1.a Graph Showing Tritium Concentration in Groundwater Monitoring Wells



In order to define the area of activation near VQ-12, one must know energy and angular distribution of the primary and secondary radiation. The amount of beam lost on the magnet must also be known. Additionally, the fluence of secondary radiation penetrating to soil varies as a function of shape, thickness and type of materials around the magnet.

In 1989, detailed computations of soil activation near a prototypical design of the g-2 target and beam dump were performed and caps were placed accordingly.[15] However, ten years later tritium and sodium-22 were detected in groundwater monitoring wells. In response, the C-AD investigated source of the tritium and initially performed detailed radiation surveys of the V line and found the VQ-12 magnet was 3 rem/h at contact on its upstream end and 1.5 rem/hr on its downstream side. This residual radiation observed at the VQ-12 was not expected. Other magnets in the V line had much lower radiation levels; about 0.01 rem/h. Secondary particles

[15] D. Beavis, "Soil Me: Soil Activation Estimates for the g-2 Target Area and Beam Dump," AGS EP&S Technical Note 135, AGS Department, Brookhaven National Laboratory, Upton, New York 11973, December 5, 1989.

created at the VQ-12 magnet were estimated (calculated) to cause activation in nearby soil shielding within a radius of 30 feet or more. Based on the radiation level on the VQ-12 magnet, it was determined that as much as 15 percent of the beam was lost at this point in the V line and a detailed assessment of the soil activation in this area commenced.

To define the activation zone near the VQ-12 magnet, soil samples were taken in November 1999. The results indicated a total activity of sodium-22 of as much as 400 mCi. Based on the ratio of sodium-22 to tritium production in soils, this implied that more than 130 mCi of tritium were created in soil in this region.

Because the soil shielding around the VQ-12 area was not protected by a cap, tritium was able to move into the vadose zone and groundwater via rainwater that percolated through the activated soil. After the cap was installed, C-AD staff reviewed records on operational run times and beam losses to calculate the amount of radioactivity that was produced in the soils. A cap over VQ-12 area was installed in mid December 1999 and from that point on, tritium accumulated under the cap until the g-2 experiment ceased operations in late April 2001. Although the cap has been effective in preventing the continued leaching of tritium from the activated soils, tritium that was transported close to water table prior to capping continues to be released to the groundwater during annual fluctuation of the position of the water table (see Figure 3.2.7.7.1.a). The highest tritium concentrations were observed in July 2002, when concentrations reached 3.4 M pCi/L.

The zones of activation were determined and mapped (see Figures 3.2.7.7.1.b, c and d). Soils having a tritium concentration of approximately >10^{-10} curies per cubic centimeter are of particular concern because if the cap were to fail and one year's average rainfall was able to leach through these soils, tritium concentrations in the leachate could exceed the 20,000 pCi/L drinking water standard. A comparison of the position of the cap to the calculated zone of activation suggests that the Gunite cap, and concrete pad on which the beam line was constructed, is adequately protecting the soils containing the highest levels of radioactivity.

Based on the g-2 experience, BNL developed a conservative standard for capping activated soil areas in order to prevent further contamination of the ground water. BNL's new beam-line design criteria calls for the capping of any activated soil area where potential leachate could contain tritium at concentrations greater than five percent of the Drinking Water Standard (>1,000 pCi/L for tritium). These criteria are described in the Accelerator Safety Subject Area (BNL, 2000). Because of this new standard, the C-A Department undertook the project to define and archive the facts regarding known beam loss locations. Because the standard calls for a cap at 20 times less than the Drinking Water Standard, the C-A Department anticipates that as the study continues, the need for additional caps may be identified.

Figure 3.2.7.7.1.b Map Showing Lines of Cross Section Through the VQ-12 Source Area

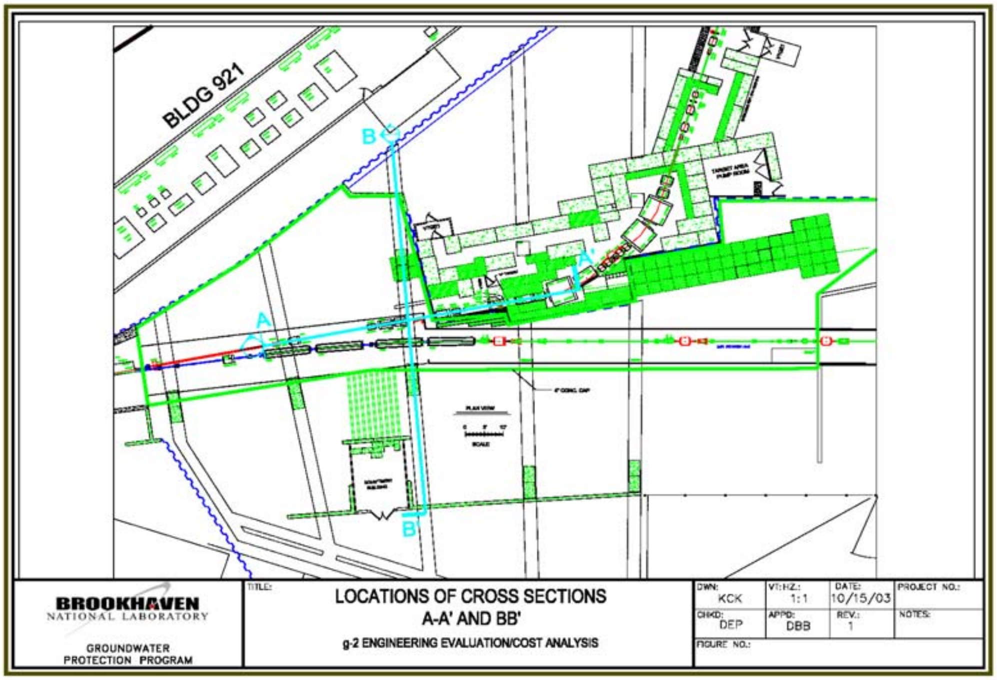


Figure 3.2.7.7.1.c North-South Cross Section A-A' which Runs Along the g-2 Beam Line

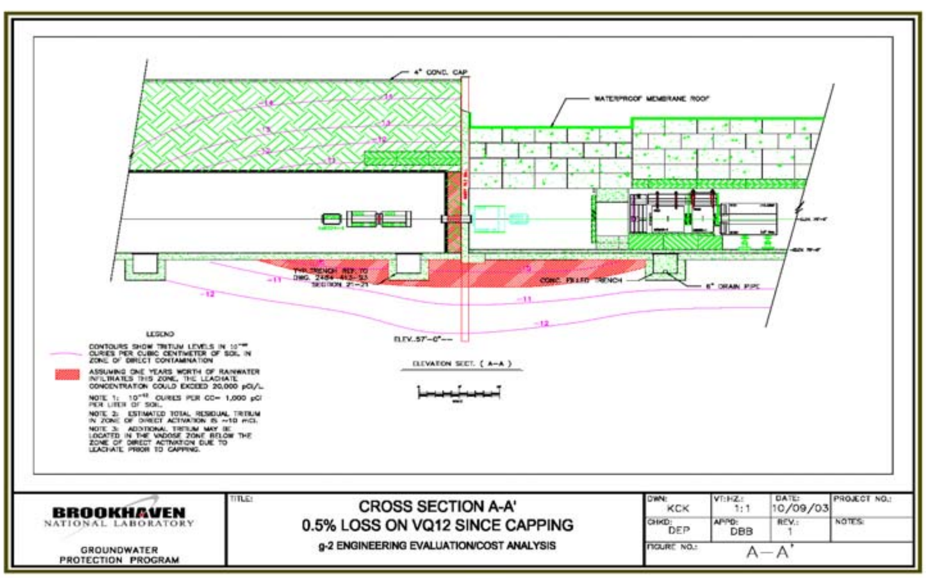
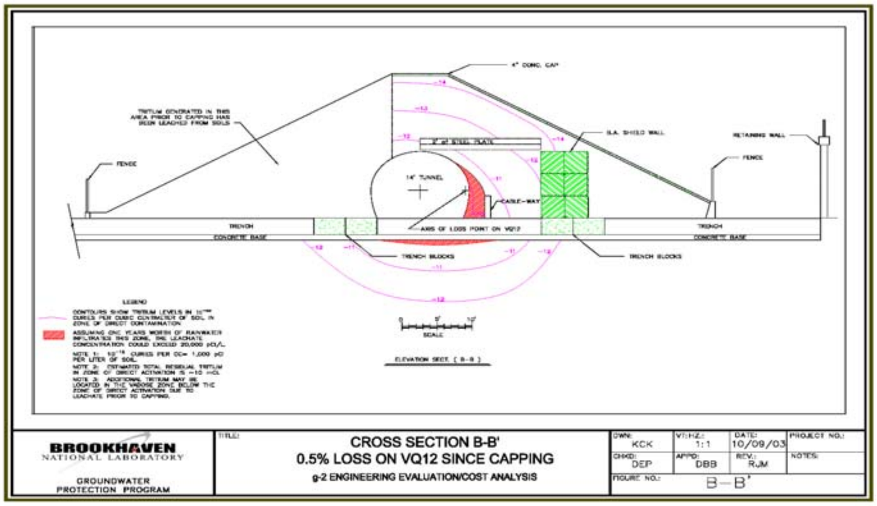


Figure 3.2.7.7.1.d East-West Cross Section B-B' Immediately South of the VQ-12 Magnet



3.2.7.8.Typical Block House Design for Fixed Targets

Figures 3.2.7.8.a and 3.2.7.8.b show a typical blockhouse used to shield high-intensity proton targets. This blockhouse was designed for the V Target. On the west side of the g-2 target there is the equivalent of 4 feet of iron that was placed to reduce the residual radiation level in aisle way inside the blockhouse. On the east side is 4 feet of iron and the U line tunnel. Four and a half feet of heavy concrete is placed below target down to floor level and 3 feet of concrete was placed on either side of the target but in a trench below floor level.

Other blockhouses at the C-A Department are further enclosed by larger buildings such as Building 912 or Building 956. See Figure 3.2.7.8.c for a view of the planned blockhouse for the KOPIO experiment in Building 912. The concrete blocks attenuate the radiation so that sky-shine radiation and direct radiation are within ALARA guidelines.

Figure 3.2.7.8.a Blockhouse Used to Attenuate Radiation

Figure 3.2.7.8.b Plan View of Blockhouse Used to Attenuate Radiation

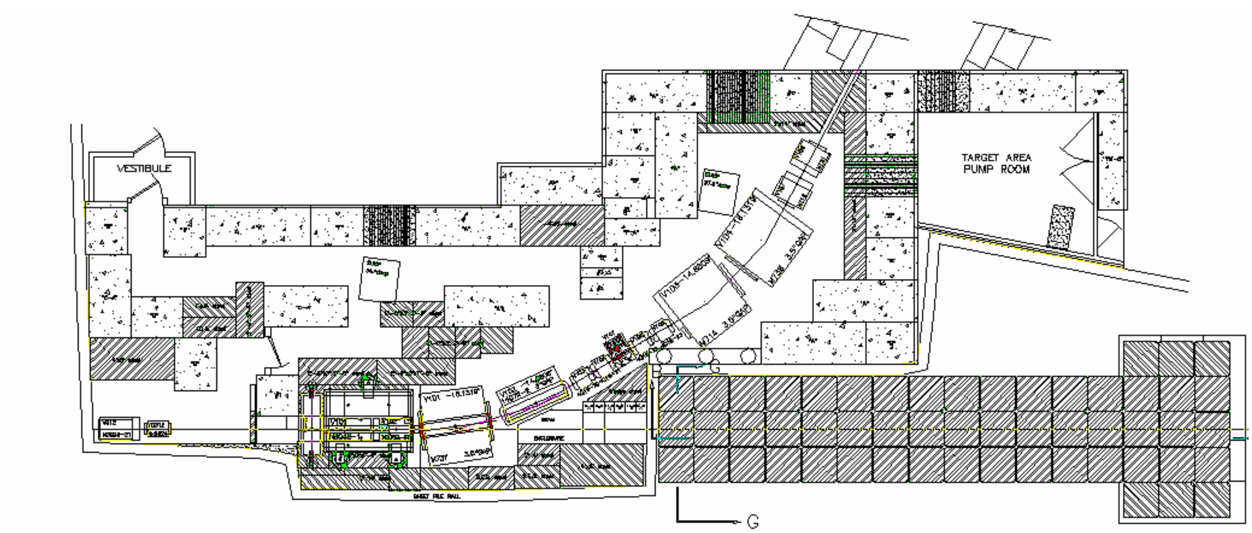
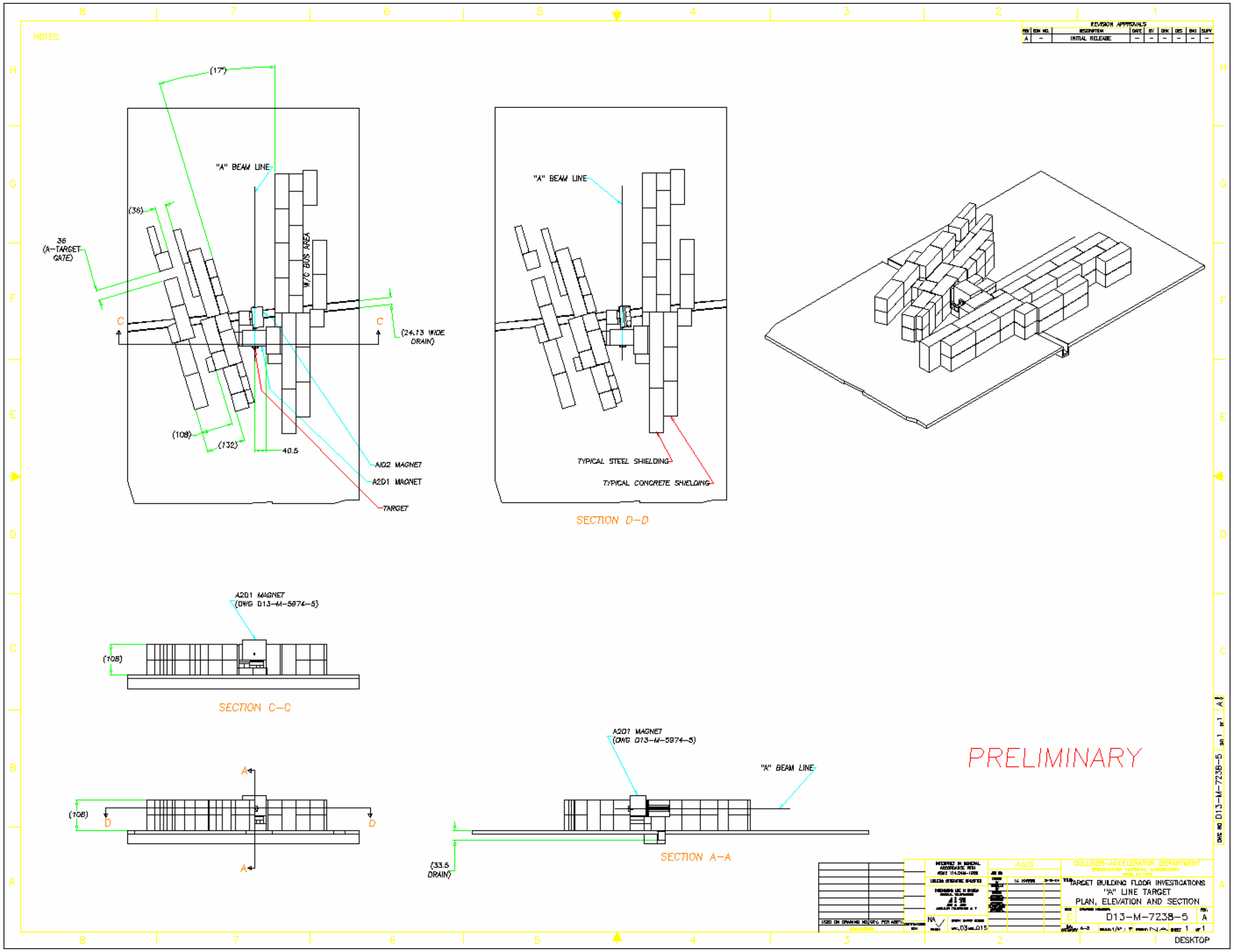


Figure 3.2.7.8.c Views of Blockhouse Used to Attenuate Radiation in A Line in Building 912



3.2.7.9. Typical Beam Dump and Re-Entrant Cavity in Experimental Areas

Beam dumps are the sinks used to absorb the energy and concomitant radiation from beams that have completed their utility. These dumps are typically made of ilmenite-loaded concrete, occasionally steel. See Figure 3.2.7.9.a for a drawing of the steel dump used for high-intensity proton running in the V line. The design often incorporates a recessed entry area, or reentrant cavity, which greatly reduces radiation shine perpendicular to the direction of the incident beam on the face of the dump. See Figure 3.2.7.9.b for an example of a re-entrant cavity at NSRL. The length and transverse dimensions of the beam dump are designed to assure that the radiation generated is sufficiently attenuated.

Beam dumps for high intensity protons may handle beam intensities up to the full capacity of the AGS, entailing an average energy dissipation of up to 90 kW for the SEB. Secondary dumps terminate a relatively small-analyzed beam of particles from a production target. Since analysis entails selection of a specific charge, or charge-to-mass ratio, and momentum bite of the total flux of secondary particles, the ‘selected’ secondary beam is orders of magnitude lower in intensity, and often lower in energy, than the primary beam, with consequently smaller beam dump dimensions.

Accumulation over time of residual radiation in beam dumps is a significant design consideration. Exposure levels of the order of tens of rem/h are common for high intensity proton beam dumps at the onset of shutdown, requiring attention to the reliability and maintainability of any nearby components.

Figure 3.2.7.9.a Plan View of V Blockhouse Showing 50-Foot Iron Beam Dump

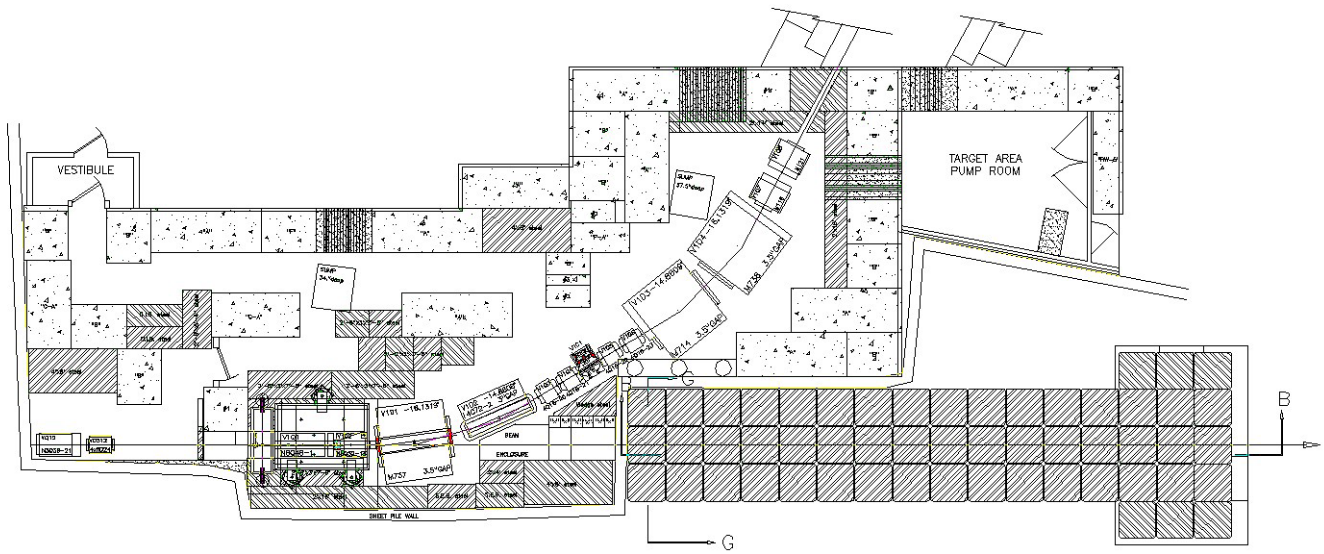


Figure 3.2.7.9.b Side View of V Beam Dump Showing Re-Entrant Cavity

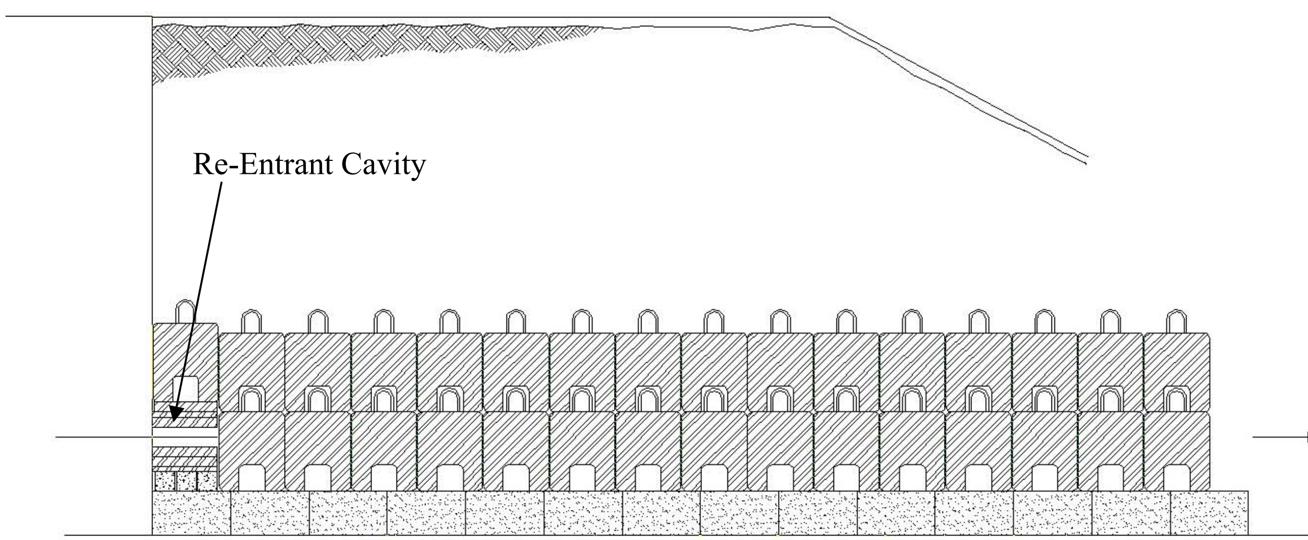
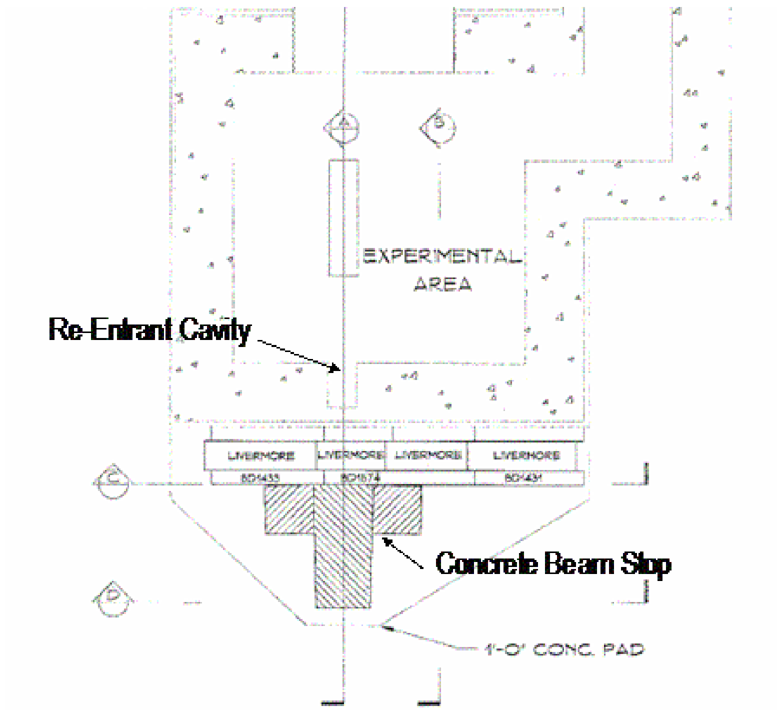


Figure 3.2.7.9.c Re-Entrant Cavity at the NSRL Beam Dump



3.2.7.10.Typical Shield Wall at a Collider Experiment

The area and height of the IRs varies. Most locations are equipped with overhead cranes that have direct access from grade. The six and eight o'clock areas have an assembly building that leads into an IR. Concrete shield walls separate these areas during the running period. The removable walls of IRs are composed of light concrete blocks. When the Collider is circulating beam, 5.5-foot thick blocks are used to form a shield wall in the IR separating it from the assembly building. See Figure 3.2.7.10.

Generally, movable shield block walls incorporate a small movable plug for personnel access, an emergency escape labyrinth and a larger movable door to allow movement of the large elements of the detector between the IR and the assembly area.

Figure 3.2.7.10 Shield Wall Enclosure at the STAR Experimental Hall

3.2.8. Design Criteria and As-Built Characteristics of Power Distribution

3.2.8.1. Substations and Transformer Yards

Standards and requirements that relate to design of substations and transformer yards are National Electrical Code, National Electrical Safety Code, National Fire Prevention Association standards, Institute for Electrical and Electronic Engineers standards, OSHA requirements, EPA requirements, National Electrical Manufacturers Association standards, Illumination Engineers Society standards, and standards developed by the American National Standards Institute.

The potential hazards associated with substations and transformer yards are electric shock, electrical short, arc-blast, oil spill, fire and clean waste disposal. Training, routine inspection, routine maintenance, personal protective equipment, secondary containment and trap rock to suppress fire are used to mitigate these hazards. Proper fuse ratings, circuit breaker settings and set points are selected to coordinate protection against faults and over loads. The nominal ambient operating temperature limit is 40 ^{o}C, and where necessary internal heaters are provided for cold temperatures. Supporting systems include batteries, the power-monitoring system and the oil/water separation weir.

A routine inspection schedule for substations and transformer yards is maintained by plant engineering, and routine maintenance is monitored by C-A Department. Maintenance procedures follow industry standards. Operational personnel need electrical safety training, and staff from Plant Engineering responds to emergencies using their standard practices.

Normal power from the power distribution system is not required for safety systems; however, the emergency power system is needed for systems that maintain property protection or prevent property loss such as cryogenic controls.

Circuit breakers are typically tested every three years. Presently, the substations are on a 2-month cycle for inspection and 2-year cycle for maintenance and testing. Comprehensive oil testing is on a three to six year testing cycle unless test results require more frequent testing per standards.

In order to minimize hazards, the transformer tanks contain mineral or silicon oil. Handling of oil is by line crew or outside oil vendor. No oil is discharged intentionally. Bi-monthly inspections of the substation are performed looking for oil leaks or spills. If transformer oil reaches soil or trap rock, the soil and rock are remove and put in containers for disposal. Industry standards are used for handling oil and oil waste.

3.2.8.2.Power Distribution

Standards and requirements that relate to design of power distribution are National Electrical Code, National Electrical Safety Code, National Fire Prevention Association standards, Institute for Electrical and Electronic Engineers standards, OSHA requirements, EPA requirements, National Electrical Manufacturers Association standards, Illumination Engineers Society standards, and standards developed by the American National Standards Institute.

The potential hazards include electric shock, electrical short, arc-blast, fire and oil spill from diesel generator tanks. Training, routine inspection, routine maintenance and personal protective equipment mitigate these hazards. Proper fuse ratings, circuit breaker settings and set points are selected to coordinate protection against faults and over loads. The nominal ambient operating temperature limit is 40 ^{o}C, and where necessary internal heaters are provided for cold temperatures. Supporting systems include batteries and power-monitoring system.

Routine inspection is through the Tier 1 inspections. Inspection and maintenance procedures follow industry standards. Operational personnel have electrical safety training. Plant Engineering inspects and tests the diesel generators and responds to emergencies.

Normal power from the power distribution system is not required for safety systems; however, the emergency power system is needed for systems that maintain property protection or prevent property loss such as cryogenic controls.

Circuit breakers are typically tested every three years. Presently, the substations are on a 2-year cycle for maintenance and testing. Diesels are test bi-monthly during the warmer months and monthly during the winter.

The diesel/generator tank contains diesel fuel oil and lube oil. Handling of oil is by heavy equipment operators or outside diesel vendor. No oil is discharged intentionally. In order to reduce hazards, bi-monthly inspections of the diesels are performed looking for oil leaks or spills, and industry standards are used for handling oil. Periodic inspection of diesel/generators is performed by Plant Engineering staff.

3.2.9. Design Criteria and As-Built Characteristics of Cooling Water Systems

Figure 3.2.9 depicts the typical two-part water-cooling system used in most CA-Department installations. The Process Water Side pulls heat from the load and transfers it to through the Heat Exchanger to the Cooling Tower Water Side, which dissipates the heat to the air via the cooling tower.

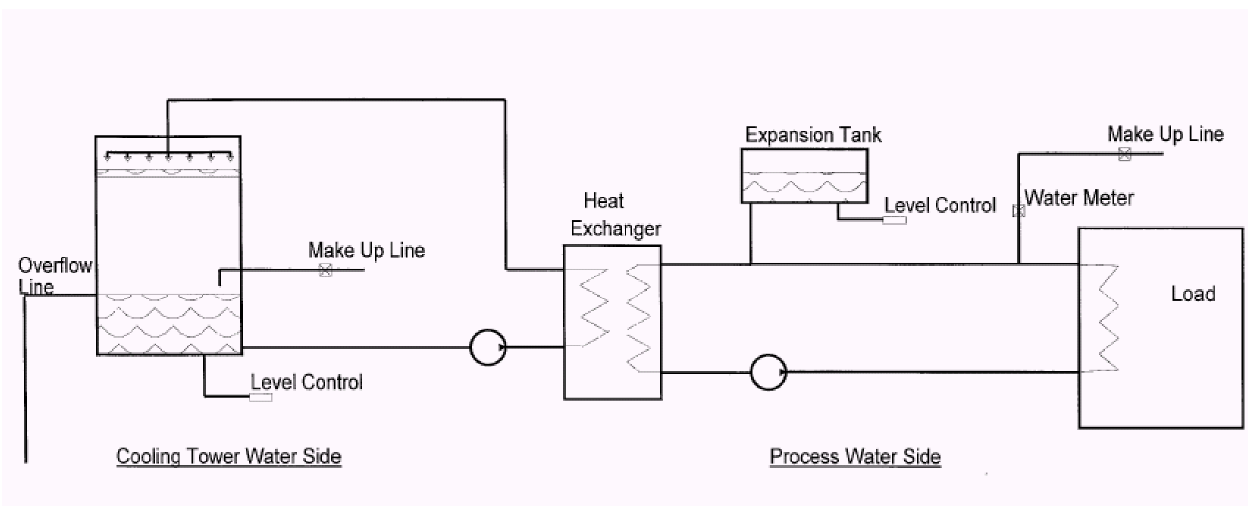
Process Water Side - The heat load is generated from several sources. The source could be from electromagnets, which may be activated by the beams, or from non-activated sources such as power supplies, electronics racks or power buss cooling. This system is completely closed loop. The water level in the expansion tank is continuously monitored using a programmable logic controller (PLC) system that measures the tank's water level, and opens and closes the valve in the Makeup Water Line at specified levels. In addition, the PLC activates alarm signals for the system operator to perform checks to determine the severity and source of any water loss. The system will automatically shut off upon activation of the second-level low-water alarm as well as other system safety parameters.

Cooling Tower Side - This system can be either a closed or an open loop tower-system but both types of tower systems would have basins that are open to air. Most basins have water that is chemically treated with biocides and rust inhibiters but some have ozone treated water systems and a few systems have no treatment at all. In all cooling tower installations, blow-down lines go either to the sanitary system or to storm drains that lead to recharge basins through water monitoring stations.

System Design Specifications - Design guidance for the water piping systems is obtained from the following standards organizations: ASTM, ANSI, ASME and MSS. Suffolk County Article 12 is also applied to all water systems that contain hazardous materials. Radioactivity is defined as a hazardous material for the purposes of Suffolk County Article 12 if the radioactivity level is above the Drinking Water Standard. Typical Article 12 requirements include:

- plans and specifications reviewed and approved by Suffolk County
- impervious secondary containment
- high level alarms to prevent overfilling
- regular documented inspections

Figure 3.2.9 Typical Two-Part Cooling-Water System



Process water has the potential to become activated. Several dedicated process-water cooling systems are distributed throughout the magnet enclosures, supplying cooling water to magnets, targets and RF cavities. Additionally, process-water systems are routed through the enclosures to cool external devices. For example, chilled water is distributed through the AGS ring to the fan houses, where it is used for the ring air-conditioning system. Before disposal, process-water is sampled for radioactivity and metals even if the water is not expected to be radioactive or hazardous. Water samples are obtained using “Chain-Of-Custody” formality and are labeled to identify date, building number and system name. If an effluent is intended, either by collecting spilled water in a sump or by draining down a system, then the sample results are used to determine if the effluent may be low-level liquid radioactive waste.

Process water in about one-third of C-A Department’s cooling systems may contain 12.3-year half-life tritium and trace amounts of other shorter-lived radioactivity; e.g., 53-day Be-7 or 14.9-hour Na-24. With the exception of Building 912 experimental-area cooling towers, process-water systems are closed and are sampled before any planned release. Process water is normally polished by ion exchange and is not changed-out very often, if at all. Ions are removed from process-cooling water because ions allow electric fields to be created around brass connections, which in turn cause the brass to be dissolved away. Major changes to process-water systems may occur every decade or so, and, in recent years, process water has been held and returned to the system after the work is done.

Leaks from primary-water systems are collected by a network of floor drains. Process water entering the floor-drain system is conducted to the sanitary sewer system directly or is collected in sumps. Sumps are alarmed using level indicators. The water is transferred to portable storage tankers and analyzed. In areas such as the Booster and the experimental area in Building 912, water leaks are conducted directly to the sanitary system. At the BNL sanitary wastewater treatment facility, ponds can hold the water if necessary. However, the total tritium in all C-A Department water systems is less than 50 mCi, and is not likely to cause measurable activity concentrations at the sanitary system outfall should activated water make its way to the floor drains. To put this amount of radioactivity in perspective, a single biomedical study at a university may involve 50 mCi of tritium.

The secondary side of closed-cooling systems is well water and cooling tower water, with the addition of treatment chemicals or treatment with ozone. Under normal conditions, the secondary water does not contain tritium. The C-A Department staff relies on a sub-contractor, to manage the chemicals used in cooling waters. The Department monitors all of the automatic systems used to add rust inhibitor and biocide, and they do the weekly analysis of chemical concentrations. C-A Department staff manages systems that use ozone, which results in no chemical additives. Secondary cooling waters are released to recharge basins on the BNL site. These recharge basins are monitored by the BNL Environmental and Waste Management Services Division to ensure that release of water treated with chemicals is within the limits of SPEDS permits.

As indicated previously, most of the process-cooling water systems are closed. There is no exchange other than heat between the primary cooling water and well water and no emissions to air. However, four cooling towers cool the process water from magnets in experimental areas in Building 912. Since these towers are blown-down continuously to maintain a constant temperature range in the magnets, tritium does not build up in the water. However, a small percentage of the dissolved short-lived radioactive gases such as 1.2 minute O-14 and 2.1 minute O-15 are emitted from the towers. Studies of radiation levels associated with emissions to air from the open cooling towers were performed in 1995. These studies showed that emissions from the towers are far below the threshold for continuous airborne radioactivity monitoring required by 40 CFR 61, Subpart H. Periodic sampling is conducted to confirm previous results, as per Subpart H.

3.2.10.Design Criteria and As-Built Characteristics of RF Systems

Particle accelerators may generate pulse powers of many megawatts and generate RF fields. In normal use, RF hazards to staff are negligible compared to those from scattered ionizing radiation. However, during maintenance work close to the magnetron or wave-guide, staff may be exposed to RF fields. Design criteria for RF systems are found in BNL Environment, Safety and Health Standard “RF and microwaves” 2.3.2. Design criteria at C-AD include:

- providing shielding and other control measures to minimize radiation leakage
- guarding exposed dummy loads to prevent burns
- providing adequately sized electrical ground connections to dissipate energy
- eliminating sharp edges or points on equipment to avoid corona discharge
- where possible, provide bypass capacitors on control power and instrument leads that enter the RF compartment to control leakage without interfering with proper operation

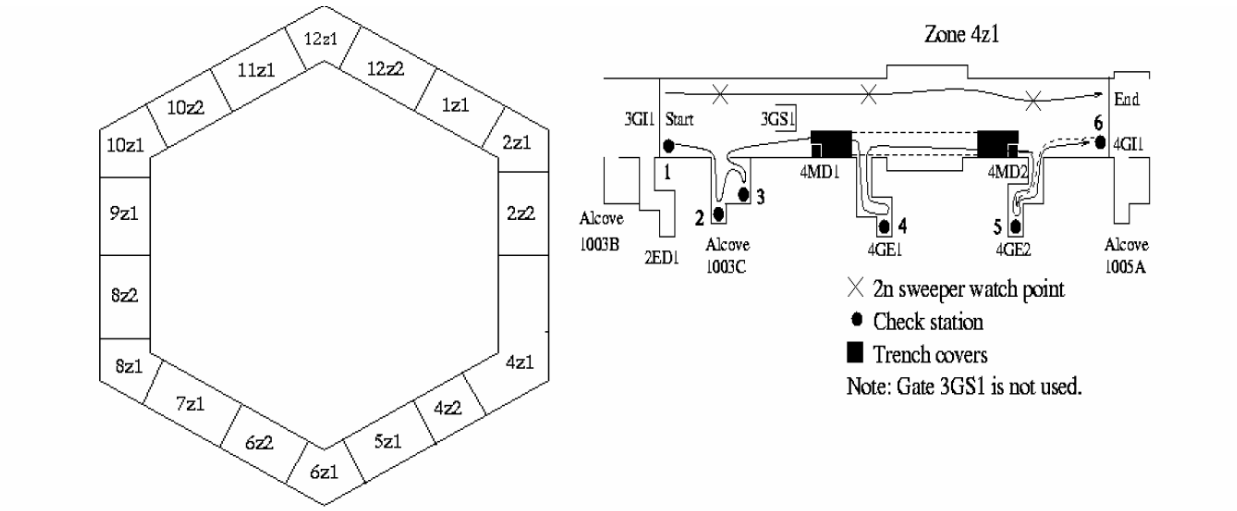
Staff may also be exposed to x-rays from high-power RF equipment, klystrons and accelerating cavities. This is the reason for restricting access to areas where high-powered RF equipment is used.

For example, The RHIC RF accelerating system is located in Buildings 1004, 1004A and the 4 o’clock sector (4z1) of the RHIC tunnel section. There are four 28-MHz accelerating cavities and ten 197-MHz storage cavities. The cavities are an x-ray hazard that has been estimated to be 100 rad/hr maximum for each accelerating cavity and 200 rad/hr maximum for each storage cavity. The absorbed dose-rate estimate is based upon test stand measurements that were extrapolated to a distance of one foot from the cavities using the inverse square law. The measurements were made under high-field emission conditions. The cavities are located the RHIC tunnel.

The 197 MHz cavity measurements were made in the labyrinth from 1004A into the tunnel. In their operating position, the 197 MHz cavities are furthest from the routinely occupied areas and there is an additional leg to the labyrinth thereby significantly reducing the transmission from the tunnel to occupied areas.

In order to allow the cavities to be powered, the 4z1 zone in the RHIC tunnel must be cleared of personnel, and this clearing process is termed a "sweep." A trained two-person team must perform the sweep. The RHIC Zone 4z1 RF Sweep Checklist (See C-A OPM Chapter 4) is used by the team to document the sweep. The sweep team carries flashlights, chains and approved padlocks for the 4MD1 and 4MD2 trench gates (see Figure 3.2.10). They also carry padlocks for exhaust fan access-doors and walkie-talkies. The sweep team clears the area and uses the appropriate sweep reset-keys to reset the area to allow power to the cavities. Prior to the sweep, the team must assure RF critical devices are safely off.

Figure 3.2.10 Sweep Routine for Enclosure to Powered RF Cavities at RHIC



3.2.11.Design Criteria and As-Built Characteristics of Vacuum Systems

Typical beam vacuum systems at C-A consist of sections of vacuum chambers isolated from the adjacent sections with electro-pneumatic gate valves. Appendages to the vacuum chambers are vacuum pumps and vacuum gauges, which are remotely operated and monitored. The operation of vacuum systems is to provide a friendly environment for the circulating beam and is typically passive such that the failure of vacuum systems will abort the beam and will not cause damage to the other accelerator components and the environment.

All the vacuum chambers are made of stainless steel, Inconel or aluminum for their good mechanical and vacuum properties and radiation resistance. The vacuum chambers are designed and fabricated to meet the accelerator physics and vacuum requirements, and are reviewed by internal and external experts in the field. Design guidance for the vacuum chambers is obtained from the following standard organization: ASTM, ANSI, AVS and ASME. Except the residual radiation on the vacuum chamber walls, there is no inherited hazard in handling the vacuum chambers. C-A Department work planning and procedures are used for removal and installation of the vacuum chambers. A few vacuum chambers and windows are made of beryllium because of its transparency to energetic particles, and the vacuum pipes are handled according to C-A Department procedures for handling beryllium.

There are two types of vacuum pumps, the roughing pumps and the high vacuum pumps. The roughing pumps consist of a turbomolecular pump backed by a mechanical pump and are used during the initial pump down of the vacuum sections. There is little environment and personal hazard in the operation of the roughing pumps. Typical high vacuum pumps at C-A Department are sputter ion pumps powered remotely with 200 mA, 5 kV ion pump controllers. The ion pump controllers are energized continuously during shutdowns. C-A Department LOTO and work planning procedures are used to secure the ion pump controllers when work is performed at or around the vacuum sections.

All the vacuum pump controllers and gate valves are protected through both hardware and software interlocks using standard C-A Department Control System controllers or commercial programmable logic controllers. The controllers generate the appropriate warnings, alarms and valve closure commands, and abort the beam whenever vacuum fault condition occurs. There is no inherent hazard in the operation of these controllers.

Several beam pipe systems, such as Booster and RHIC rings, require bake out at elevated temperatures, typically 250 ^{o}C, in order to outgas the beam pipe for operation at greater vacuum. The main hazards during bake out periods are the use of high voltage and the potential for burns and fire. NEC and NFPA codes are followed. Trained personnel used C-A Department procedures and instructions include local posting and sending a notification to the Fire Captain. The notification describes the location and length of the bake out period. Bake out periods may last for several weeks. Beam pipe bake outs occur infrequently, and usually occur only at the startup of a new or significantly modified system.

3.2.12.Design Criteria and As-Built Characteristics of Radioactive Materials Bldg.

This a single story 22,500 square foot rigid frame structure to house radioactive concrete shielding block, tritiated water storage tanker trailers, and tritiated water drum and resin storage. The structure has a secondary containment foundation system. In addition to following the requirements in Suffolk County Article 12 for the water storage areas, AISC, AWS, RCRBSJ, ASTM, SSPC, ANSI and NFPA standards and codes were followed for building construction.

Ordinary and heavy concrete shielding blocks ranging in length from 1 to 30 feet and from 0.5 to 10 feet in the other dimensions are stored in this facility. Transfer is affected by crane. Transport is accomplished by vehicles of various sizes as required. Although activated, these shielding blocks represent significant investment and resources for the C-A Department.

The C-A Department operates many cooling water systems in support of the operations of the various accelerators, collider and experiments within the C-A facility. Some of this cooling water removes heat from components that are subject to interaction with primary or secondary beams. Because of this, some of the cooling water becomes activated with short-lived and long-lived radionuclides.

In order to reduce liquid waste volumes, activated water is stored in tanker trailers that are part of the cooling water process system for potential reuse. For example, if a component must be replaced in a cooling water system or a cooling water system design modified, the system water is drained into the tanker for storage during repairs or modifications and transferred back into the system when repairs/modifications are completed. This recycling is a pollution-prevention waste-minimization activity, a desired activity of the BNL Environmental Management System. Water from any of the many cooling waters systems may be co-mingled in these tankers. This water is maintained for reuse and is not routinely discarded.

It is noted that all C-A Department water processes, including tanker use, are reviewed and documented under the C-A Department's Environmental Management System. Each process has an Environmental Management Program, an Environmental Training Program, Procedures and Operational Controls. Each year, independent auditors examine C-A Department's Environmental Management System in order to maintain ISO14001 registration.

The Radioactive Materials Storage Building meets all Article 12 requirements and has a roof so that rainwater will be kept out of the tanker's secondary containment system. The floors are impermeable to water and are sloped toward a trench that can hold 110% of the volume of any tanker. The facility is equipped with communications for alarms and a steam heater to provide freeze protection for the tankers.

3.3.Design Features and Processes that Minimize Hazards

The design features and processes that minimize the presence of hazardous environments and ensure radiation exposures are kept as low as reasonably achievable during operation, maintenance and facility modification are summarized as follows:

Radiological Hazards

- dual, fail-safe interlocks are used on gate entrances (if >50 rem/hr)
- interlocked access-key-trees are used to capture gate access keys
- bio-identification systems are used to release an access key to a trained individual
- crash cords and/or crash buttons are mounted inside accelerators, intersecting regions, target caves and beam lines
- interlocking area radiation monitors with pre-set trip levels are located throughout the complex
- audible and visual warnings are issued before re-enabling an accelerator, beam line, intersecting regions, or fixed target area to receive beam
- accelerators, intersecting regions, beam lines and target areas are fully enclosed to prevent access during operations
- fencing and/or barriers are used to limit access to radiological areas
- shielding is thick enough to prevent exposure to primary beam
- multi-leg penetrations and labyrinths are used to minimize routine radiation levels
- re-entrant cavities are used to minimize exposure to residual radiation from beam dumps

Oxygen Deficiency Hazards

- warning signs posted at entrances to areas classified as ODH
- ODH training required for persons working in ODH Class 0 or greater
- medical approval required for ODH-qualified personnel working in ODH Class 1 or greater
- personal oxygen monitor for staff working ODH Class 1 or greater
- self-rescue supplied atmosphere respirator for staff working ODH Class 1 or greater
- automatic ventilation fans turn on if oxygen deficiency occurs in the RHIC Ring
- audible and visual warnings if sensors record O_2 levels below 18%

Electrical Hazards

- there are no exposed conductors; all magnet buss work has covers
- the National Electric Code is enforced for all facility electrical distribution systems
- in-house-built electrical devices are reviewed for compliance with the National Electric Code by the Chief Electrical Engineer according to C-A OPM procedure
- fusing and other protective circuitry are used in experimental equipment in accord with C-A OPM procedures
- accountable key systems, such as captive key or Kirk Key where a key must be physically removed from one position and inserted in another lock to provide access, are used in accord with SBMS/BNL ESH Standard requirements
- there are emergency-off controls for power

Life Safety and Fire Protection

- manual fire alarm stations are located adjacent to exterior exit doors
- fire detection, in the form of smoke detection, is located throughout the facilities

- fire alarms are provided throughout the facilities
- fire sprinkler protection is located in areas of high value
- fire department hose standpipes are located at the entrances to facilities.
- wet pipe sprinkler systems are hydraulically designed for 0.15 gallons per minute per square foot over 2500 square feet of the most remote area
- wet pipe sprinkler systems are hydraulically designed for 250 gallons per minute for hose streams
- exits meet the requirements of the Life Safety Code
- the use of flammable liquids is minimal and any use of flammable liquids follows SBMS requirements
- any use of flammable gases follows SBMS requirements
- emergency lighting is provided throughout the complex
- fire extinguishers are provided throughout the complex with 75 feet as the maximum travel distance to an extinguisher

Hydrogen Targets

- target windows are tested against puncture
- target vacuum sensor and hydrogen detectors are interlocked to the power supply to nearby experimental detectors
- upstream and downstream experimental detectors and chambers are protected with fire wire and smoke detectors
- fire wire and smoke detectors interlock the electric power to the experiment and cause alarms to go off alerting both MCR operators and the target watch

- before a target installation, the environment around the target is reviewed for potential ignition sources (pre-amps, cabling, power-supplies, gas flow systems, detectors and detector chambers are examined)
- written procedures are required to operate experimental chambers and gas systems around the target
- routine portable sampling for hydrogen or any other flammable gas in use near the target is required before startup and following shutdown
- voltages on experimental equipment are required to be on before hydrogen or deuterium is introduced to the target
- alarm responses are written into formal procedures and the target watch is trained, again before the introduction of hydrogen or deuterium to a target
- work on or around the target is forbidden unless the hydrogen or deuterium is removed
- fire wire and smoke detectors are required to be operational at all times or the hydrogen is vented off
- failed smoke detectors are not bypassed while the target is in operation

3.4.Design Features and Processes that Prevent Pollution

To provide excellent science and advanced technology in a safe and environmentally responsible manner the C-A Department reviews the aspects of its operations in an effort to identify pollution prevention opportunities and accomplish waste minimization. This process began in 1988 with the development of formal environmental design guides and a design review process at C-A Department. More recently, this program, now called Environmental Management System (EMS) has met the requirements of ISO 14001. Based on the aspect identification and analysis process in the SBMS, the following environmental aspects are significant to C-A Department operations:

- regulated industrial waste
- hazardous waste
- radioactive waste
- mixed waste
- atmospheric discharge
- liquid effluents
- storage/use of chemicals or radioactive material
- soil activation
- PCBs
- water consumption
- power consumption
- environmental noise

BNL's Facility Review Project and the Process Evaluations, which were initially conducted in 1999, served as the technical baseline through which significant aspects at C-A Department were systematically identified. The C-A Department reviews Process Evaluations annually or as required if a process is changed, and updates the EMS documentation when appropriate.

The C-A Department assures that environmental goals in the BSA contract are achieved and that C-A Department activities are in accord with regulatory requirements. Annually, the contract-derived environmental objectives and targets are documented in the C-A Department EMS for each process and the responsibility for achieving specific environmental objectives is assigned to staff. Meeting regulatory requirements is assured by involving one of BNL's Environmental Compliance Representatives (ECR) in the evaluation of work tasks and in the review of experiments. C-A Department environmental objectives and targets also incorporate objectives and targets recommended through senior management reviews of the C-A Department EMS. Due to the nature and scope of C-A Department operations, there are two ongoing environmental objectives: prevention of groundwater contamination from activated soils, and reduction of legacy materials produced by past experiments.

On a day-to-day basis, the C-A EMS is executed through safety reviews and work planning. The ECR serves on both the Experimental Safety Review Committee (ESRC) and the Accelerator Systems Safety Review Committee (ASSRC). It is the responsibility of the ECR to review activities for implementation of environmental controls and to add or revise C-A environmental aspects as required. Identified EMS action items are incorporated into the work planning process, or are closed out in the experiment or accelerator-modification review and approval process.

Formal training and qualification programs for the operation of equipment, processes and procedures that could have a significant impact on the environment are documented. At C-A Department, job-specific training is developed for environmental processes that involve significant aspects. Employees that interact in these processes are required to go through training.

Internal communication of significant aspects and EMS strategies occurs through a schedule of weekly planning meetings. During these structured meetings, involving appropriate personnel, work is planned and evaluated, concerns of safety, equipment, hazards and environment are addressed and resources are allocated. External communications includes correspondence with regulators, DOE-BHSO, suppliers, customers, civic groups, elected officials, public and the media. External communications regarding EMS is also posted on the web.

The C-A Department document control system, which includes EMS documents, is developed in compliance with Laboratory requirements is SBMS. In addition, C-A Department records are managed through implementation of SBMS requirements. The C-A Department has identified all significant operational, environmental, safety, health, training and quality records.

The C-A Department has an established emergency preparedness and response plan. This plan is detailed in the OPM Chapter 3 and is intended to provide general guidance for use in responding to most incidents, which may arise at C-A Department facilities. In addition to the plan, specific procedures for reporting and mitigating environmental impacts are in the OPM Chapter 10.

The C-A Department documents its environmental nonconformance, corrective, and preventive actions primarily through ORPS. All non-ORPS events are documented using the SBMS Subject Areas on “Critiques” or “Nonconformance & Corrective and Preventive Action.”

Assessments and audits are used as the basis for examining, identifying and correcting weaknesses within the C-A Department EMS program to facilitate improved performance and compliance. EMS audits are scheduled, performed and tracked through the Assessments and Tracking System (ATS) database. C-A Department EMS audits are conducted, at a minimum, annually.

As a routine part of operations, C-A Department managers conduct reviews of EMS. These meetings are held both weekly and monthly. Annually, the C-A Department EMS is reviewed with BNL senior management. The senior management review is accomplished in accordance with the provisions of the SBMS.

Because of EMS and prior environmental protection programs at C-A Department, many design features and processes that ensure pollution prevention were developed and implemented. They are summarized as follows:

Liquid Effluents

- sumps and sump alarms are located appropriately to capture cooling water should it leak
- all drain piping in facilities is either connected to sumps or connected to the BNL Sanitary Sewage System
- all cooling water systems have water make-up alarms
- make-up water to activated cooling systems is tracked by computer and records are retained
- outdoor tritiated water piping or cooling systems have been eliminated with few exceptions; the exceptions have secondary containment
- isolated closed cooling-water systems are used to reduce the total volume of tritiated water
- connections to the domestic water supply are equipped with back-flow preventers

- secondary containment is used in compliance with Suffolk County Article 12

Airborne Effluents

- hoods and individual laboratory ventilation with filters are used for laboratory work with radioactive and hazardous materials
- air and short-lived (minutes) airborne radioactivity are re-circulated in accelerators, beam lines and most target areas to allow for radioactive decay of airborne radioactivity *in situ*
- fixed target areas for heavy-ion experiments are exhausted to minimize exposure to experimenters who must make frequent entries; however, airborne emissions from these low-intensity target-areas results in less than 0.1 mrem per year to the maximum exposed member of the public
- short-lived airborne radioactivity may be emitted from cooling-water towers near Building 912 fixed-target experimental areas; however, airborne emissions from C-A Department cooling-water towers results in less than 0.1 mrem per year to the maximum exposed member of the public
- tritium air emissions result from recycling process-water held in water tankers that are heated for freeze protection in the cold weather; however, airborne emissions from C-A Department water tankers results in less than 0.1 mrem per year to the maximum exposed member of the public

Activated Soil Areas

- activated soil and areas where soil activation is anticipated to cause the groundwater to receive leachate that exceeds 5% of the DWS are capped with impermeable barriers

- the maximum allowable rainwater infiltration rate through the cap is designed to be less than 0.3% of the infiltration rate for natural, uncapped soils at BNL
- the long-term average infiltration rate through the cap is designed to be less than 0.2% of the natural groundwater recharge rate at BNL
- environmental issues are reviewed by the RSC and ALARA committees and they review soil activation, air activation, ground water activation and erosion of soil shielding
- RSC and ALARA committees determine position of protective caps that prevent rainwater leaching of the activated soil, and they review groundwater activation and airborne activity estimates

Steel Storage Yard

- quarterly inspections of areas are performed as part of the Tier I process to assure that materials are visibly clean, and intact with no evidence of corrosion or flaking
- steel handling equipment (forklifts/cranes) is routinely checked for evidence of fluid leakage

Shielding Storage Yard

- quarterly inspections of areas are performed as part of the Tier I process to assure that materials are visibly clean, and intact with no evidence of corrosion or flaking
- shield handling equipment (forklifts/cranes) is routinely checked for evidence of fluid leakage

Radioactive Materials Storage Building

- secondary containment is used in compliance with Suffolk County Article 12
- the portable storage container area is designed in compliance with Suffolk County Article 12
- all drain piping is either connected to sumps or connected to the BNL Sanitary Sewage System
- indoor storage by design keeps outside elements from degrading shielding blocks and additional material otherwise stored outside

Storm Drains

- all drainage has been redirected either to a recharge basin or to the Sewage Treatment Plant
- a listing of liquid effluents and discharge points by building was prepared as part of the Facility Use Agreement (FUA)
- recharge basins are sampled on a scheduled basis to assure that all releases are within the State Pollutant Discharge Elimination System (SPDES) Permit
- excursions beyond any allowable limits are reported to the appropriate regulatory agencies and immediate remedial action is taken

Sanitary Sewer System

- the Sanitary sewer system is continuously monitored to verify compliance with the State Pollutant Discharge Elimination System (SPDES) Permit levels
- excursions beyond limits are investigated and corrective action is taken
- in the event of an accident or a potentially unwanted discharge, the Sewage Treatment Plant has the capability to divert the discharge into large holding ponds and take appropriate actions to remediate the “held” discharge

Tanks That Contain Petroleum or Toxic or Hazardous Materials

- labels are conspicuously displayed on the tank
- associated piping is labeled at the point of building penetration and at points of filling or drawing
- records of product delivery and consumption are maintained for five years
- daily inspections are performed on tanks, piping and secondary containment systems for evidence of spillage or leaks
- leaks are investigated immediately and corrective actions performed to repair the system
- monthly checks are performed on leak detection and hi-level monitoring systems, and inspection of the condition of the tank system and secondary containment
- records of checks are maintained for five years
- inoperative systems or system deficiencies are repaired immediately and noted in the record
- cathodic protection systems are tested annually
- when required, routine tightness tests of piping are performed and all tightness testing is performed in the presence of Environmental Compliance and Suffolk County personnel

Water Consumption

- water consumption is minimized, when feasible, through the re-use of system water when a system is drained
- C-A has minimized its use of once through cooling water in its systems
- the Main Magnet water system's heat exchanger is equipped with a regulator and valve to allow on-demand cooling and minimize water consumption

Power Consumption

- procedures in the C-A OPM assure that power consumption is monitored, controlled and minimized
- monthly electrical power limits are set for the C-A Department
- daily power usage is monitored by the C-A Department
- a protocol is in place to shed unnecessary electric loads when an experiment is ended, and when the power is no longer needed for safety, equipment testing or maintenance
- electrical power usage is reviewed annually for implementation of new engineering controls or standard operating procedures

Radioactive Materials Storage Areas

- all liquid wastes are kept in secondary containment
- all bins and bags are kept closed or sealed
- materials are segregated and labeled to eliminate improper disposal
- large storage areas are inventoried and inspected at a minimum of yearly; most areas more checked more frequently via the C-A Department Tier I process and the BNL FS Group

- wherever reasonably achievable, radioactive materials are stored indoors to avoid interaction with the environment

Chemical Storage Areas

- all chemicals are labeled to avoid improper uses and accidents that would affect the environment
- chemicals are stored in fireproof cabinets and in secondary containment
- spent chemicals and fluids are placed in satellite accumulation areas in sealed labeled containers for appropriate disposal, which is in accordance with the SBMS
- Tier I inspections include a review of chemical storage in each area
- deficiencies such as insufficient labeling and inappropriate storage are corrected during inspections by the C-A Environmental Coordinator, and/or C-A Environmental Compliance Representative

Hazardous, Radioactive and Mixed Waste

- the most significant pollution prevention activity performed by the C-A Department is in the recycling and reuse of radioactive beam-line components
- magnets, bus work, cable trays, steel, cable, vacuum pipe, beam instrumentation and shielding blocks are reused
- any material not classed as hazardous, radioactive or mixed is disposed of through area recycling companies
- all liquid waste is kept in secondary containment
- all bins and bags kept closed or sealed
- materials are segregated and labeled to help eliminate improper disposal

- to avoid unnecessary shipments of waste, where possible, oils are recycled and burned through the Central Steam Facility for power generation
- an evaluation is performed to see if any material can be reused or recycled before putting it into a waste stream

PCBs

- PCB inventory is replaced with non-PCB items where appropriate and applicable
- PCB's and equipment with PCB's are checked in routine intervals for leakage and labeling
- equipment with PCB's and spare PCB's are in secondary containment
- ADS funds and Pollution Prevention funds requested to replace PCBs

Noise Areas

- the C-A Work Planning Manager performs noise assessments where required and stipulates the appropriate hearing protection for workers within the area
- laboratory management has been sensitive the community's concerns over noise created by RHIC compressors
- the C-A Department has reviewed designs of new facilities and modifications to older facilities to minimize and redirect noise whenever compressor building doors are open
- C-A has put a policy in place to have the doors open only during reasonable daylight hours of operation

3.5.C-A Department's Organization

The C-A Department is administered and organized to assure safe operation in accomplishing its mission. Its mission is to:

- excel in environmental responsibility and safety in all department operations
- develop, improve and operate the suite of proton/heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL
- support the experimental program including design, construction and operation of the beam transports to the experiments plus partial support of detector and research needs of the experiments
- design and construct new accelerator facilities in support of the BNL and national missions.

In meeting its mission, the C-A Department is under a formal Conduct of Operations Agreement with the Department of Energy.[16] The documentation used to comply with this agreement is the C-A Department Operations Procedure Manual, Collider-Accelerator OPM,[17] which specifies key procedures, chain of command, authorized personnel and other operational aspects. The process used to assure that personnel are qualified in safe operations is an extensive training program, including formal examinations to certify operational qualifications where appropriate.

The C-A Department organization[18] is comprised of four Divisions, the Accelerator Division, the Experimental Support and Facilities (ES&F) Division, the Controls Division and the Environmental, Safety, Health and Quality (ESHQ) Division. It is the responsibility of the

[16] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement
[17] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm Operations Procedure Manual
[18] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Organization Chart

Accelerator Division to bring two motor generators, the Siemens motor generator or Westinghouse motor generator, and seven accelerators, two Tandems at TVDG, Linac, Booster, AGS and two rings at RHIC on line and to integrate the operation of these machines into that of the complete facility. The beams from the operation of the seven accelerators must be transported by operations through transfer lines: Tandem to Booster (TtB), Linac to Booster (LtB), Booster to AGS (BtA) and AGS to RHIC (AtR), and to experimental areas. Beams must also be transported to experimental areas: TVDG Target Rooms, NASA Space Radiation Laboratory Target Room, Building 912 experimental areas, Building 919 experimental area and RHIC intersecting regions. It is the responsibility of the ES&F Division to plan, design, build and maintain the primary and secondary experimental beam lines and provide technical support for instrumentation for experiments or accelerators. It is the responsibility of the Controls Division to provide software development and hardware support for the accelerators. It is the responsibility of the ESHQ Division to provide environmental protection, safety and health related services to the staff and experimenters. The ESHQ Division provides technical work products, training services, referrals to outside professionals, documentation services, conventional and radiological safety services, environmental management, waste management and internal assessment resources to help resolve problems and meet requirements.

3.5.1. Operations Organization Introduction

The RHIC, AGS, Booster, Linac and Tandem Van de Graaff accelerators operate through the C-A Department Main Control Room in Building 911. The C-A Department's organization for operations is pictured in Figure 3.5.1. Responsibility for the safe and reliable operation of the C-A Department complex resides with the on-duty Operations Coordinator. The Operations Coordinator is the shift supervisor for the operating personnel and the focus for all operations related questions. Aside from accelerators, the Collider-Accelerator complex is made up of a number of facilities that include the motor generators, water systems, RF acceleration system, vacuum system equipment, injection equipment, extraction equipment, cryogenic equipment, transfer lines, beam lines, target halls and the experimental areas. Personnel that are responsible for the day-to-day operations of these facilities are members of the Accelerator Division, the ES&F Division, the ESHQ Division and the Controls Division. Additional personnel who support the operations are members of BNL's Radiological Controls Division, Environmental and Waste Management Services Division and Plant Engineering Division.

Depending on operations, personnel available to the Operations Coordinator during operations may include:

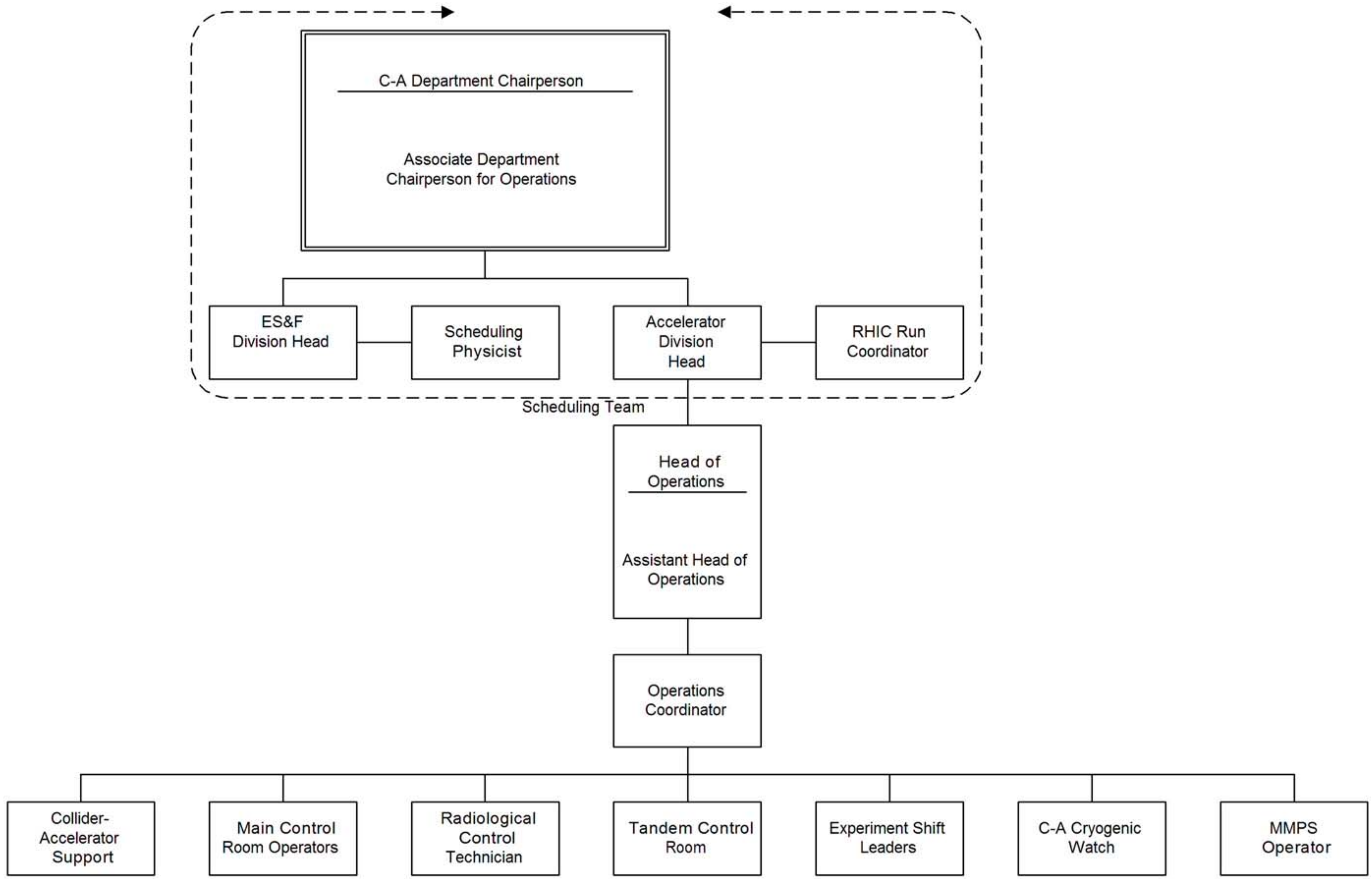
- the Main Control Room Operators
- the Collider-Accelerator Support who are responsible for accelerator and experimental area systems and beam line components
- TVDG Control Room Operators
- Power Room Operator who is responsible for the control of the AGS Main Magnet Power Supply
- Cryogenic Target Watch who are responsible for the operation of the liquid cryogenic targets, if any

- Cryogenic Control Room Supervisor and Operators who are responsible to operate the refrigeration systems for cooling cryogenic magnets
- Radiological Control Technician
- Experiment Shift Leaders at the collider experimental areas
- lead experimenter at the fixed-target experimental areas

Additional personnel available to the Operations Coordinator include the accelerator physicists and equipment systems specialists. Accelerator physicists are scientific personnel trained to be familiar with the theory and/or practice of the physical processes underlying the operation and performance of the Linac, TVDG, Booster, AGS, RHIC and the accelerator systems in the experimental areas. Systems specialists repair equipment necessary for operations or provide trouble-shooting expertise when machine physics or equipment problems arise. Occasionally, it is necessary that parts of the accelerator complex be operated by accelerator physicists or systems specialists. The rules governing access to accelerator controls, by such individuals, are found in the Collider-Accelerator OPM. In order to be allowed access to accelerator controls, accelerator physicists and systems specialists must:

- recognize the role of the on-duty Operations Coordinator as the decision-maker regarding the safe and reliable operation of Collider-Accelerator facilities
- follow the orders of the Operations Coordinator, or his designate, during an emergency
- not operate any access-control-system consoles unless authorized to do so by the Access Controls Group Leader
- request permission to use the accelerator controls and state the purpose for the use of the controls to the on-duty Operations Coordinator.

Figure 3.5.1 C-AD Operations Organization



3.5.2.Operations Authority

Safe operation and maintenance of the C-A Department's science and technology (S&T) machines, injection systems, and experimental areas are under the supervision of the C-A Department Chair, the Accelerator Division Head, the Experimental Support & Facilities (ES&F) Division Head, the on-duty Operations Coordinator and the supervisory structure. See the Collider-Accelerator Organization Chart.[19]

Only authorized Department personnel operate the S&T machines. Direct daily supervision of shift operations is the responsibility of the on-duty Operations Coordinator. All Operators are authorized to shut down the S&T machines whenever an unsafe condition arises, or whenever they think that continued operation is not clearly safe. They are also authorized to take any other corrective safety- or environmental-protection-action as indicated in the Collider-Accelerator OPM. All scheduled operational-related maintenance is done with the authorization of the appropriate Work Coordinator, with the work-control authorizations prescribed in the Collider-Accelerator OPM and with the knowledge of the on-duty Operations Coordinator.

All operations have the appropriate authorization. Current holders of positions are denoted in the Collider-Accelerator Organization Chart. The following operations authorities are listed in the OPM:

- Department Chair authorization
- Associate Chair authorization
- Assistant Chair authorization
- Division Head authorization

[19] http://www.rhichome.bnl.gov/AGS/Accel/SND/OrgChart/OrgChart.pdf C-A Department Organization Chart

- Group Leader or Supervisor authorization
- authorization to operate systems
- accelerator startup or restart authorization
- work control authorization
- Maintenance Coordinator authorization
- authorization to classify, remove or designate approval for procedures
- Department Chair, Division Head, Group Leader, committee chair and QA authorization of procedures
- committee membership and organization chart authorization
- modification of training authorization
- authorization to approve QA level classifications
- authorization to approve purchase requisitions and intra-laboratory requisitions for ESHQ compliance
- authorization to declare systems as "critical"
- authorization to approve working hot permits and procedures
- authorization to approve lock and tag checklists
- authorization to approve experiments
- authorization to approve new or modified accelerator systems
- authorization to approve new or modified shielding and access control systems

3.5.3.Administration and Organization of ESHQ

The administration of ESHQ at C-A Department is via a hierarchy of documents: BNL Policies, BNL Standards of Performance, R2A2s, BNL Management Systems, BNL Subject Areas, Safety Analysis Document, Accelerator Safety Envelope, C-A Department Conduct of Operations Agreement, C-A Department Facility Use Agreements, and at the working level, department procedures (Operations Procedures Manual).

BNL ESHQ Policies are the highest-level statements of BNL organization's philosophy for conducting business in a safe and environmentally sound manner. The number of policies is small. Policies are intended to form the complete set of foundational philosophies upon which the Laboratory operates.[20]

Standards of Performance are BNL "requirements" underlying Laboratory-wide procedures. Standards of Performance are intended to set performance expectations for BNL systems, managers and staff in accomplishing BNL Policies. By definition, the term "staff" includes all BNL staff and managers. Standards of performance also apply to those guests, visitors and users who have a guest number and have a DOE photo identification badge. Standards of Performance are high-level behaviors by which BNL carries out its policies, and are used to determine whether we are conducting our business and ourselves consistently with our mission, values and aspirations.[21]

[20] https://sbms.bnl.gov/policies/cl00d011.htm BNL Policies
[21] https://sbms.bnl.gov/perform/gstdd011.htm BNL Standards of Performance

The role, responsibility, accountability and authority statements (R2A2s) establish the expectations and duties of managers and staff for carrying out the work consistent with external and internal requirements.[22]

Management Systems are designed to translate the full set of external requirements into the information staff need to perform their work. Management systems are BNL's highest-level operating and business processes.[23]

Subject Areas are prepared when the requirements, procedures and guidelines apply to a broad group of staff across BNL. [24] If information only applies to a select or small group of staff, alternate methods of communications exist, such as task- or group-specific internal operating procedures. Subject Areas provide Laboratory-wide procedures and guidelines. They are developed to support the implementation of Standards. In some cases, specific program description documents are used as the basis for operations by discrete groups of BNL staff that perform key activities to operate the processes and systems. In the case of the C-A Department, the basis for operations is defined in the Conduct of Operations agreement[25], the Safety Analysis Document and the Accelerator Safety Envelope.

A Facility Use Agreement (FUA) is also established for C-A Department Facilities. The C-A Department Chairman, the Assistant Laboratory Director for Facilities and Operations and the Deputy Director of Operations are the agreement parties for the FUAs. The FUAs clearly documents the respective roles, responsibilities and authorities for the C-A Department Chair and the Assistant Laboratory Director for Facilities and Operations for all aspects of facility operations. The DOE approved safety/authorization basis document for C-A Department accelerator facilities, which is the Accelerator Safety Envelope (ASE), is a referenced attachment

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[22] https://sbms.bnl.gov/standard/0x/0x00t011.htm Roles, Responsibilities, Accountabilities and Authorities
[23] https://sbms.bnl.gov/mgtsys/ms00t011.htm Management System Descriptions
[24] https://sbms.bnl.gov/standard/0000t011.htm Subject Areas
[25] http://www.rhichome.bnl.gov/AGS/Accel/SND/conductofops.htm Conduct of Operations Agreement

to the FUA. Facility Use Agreements (FUAs) define the operating boundaries/requirements including roles and responsibilities for the various C-A facilities.[26]

Internal operating procedures include task- or group-specific procedures that are used to implement management system processes. C-A Department procedures typically affect only C-A Department facilities. The Collider-Accelerator ESHQ Division ensures that Operations Procedures are current and that they are based on the Laboratory-level governing documents[27] and the DOE approved SAD/ASE.

Each individual at the C-A Department is responsible for knowing and observing the rules. If any trained personnel observe any potential hazards, environmental problems or safety problems, then they must stop the work or activity and report it. Supervisors are responsible for all activities conducted within their facilities. C-A Department managers are committed to providing a safe and healthy working environment for all staff; protecting the public and the environment from unacceptable environmental, safety and health risks; operating in a manner that protects the environment by applying pollution prevention techniques to current activities; and remediation of environmental impacts of past operations.

All Collider-Accelerator personnel are knowledgeable in applicable procedures located in the Collider-Accelerator Operations Procedures Manual (OPM). The OPM is designed to be a controlled document and to conform to quality assurance requirements set down in the Collider-Accelerator Quality Assurance Procedures.[28]

The C-A Department ESHQ organizations are indicated in Figure 3.5.3. Several key ESHQ organizations and programs are described as follows:

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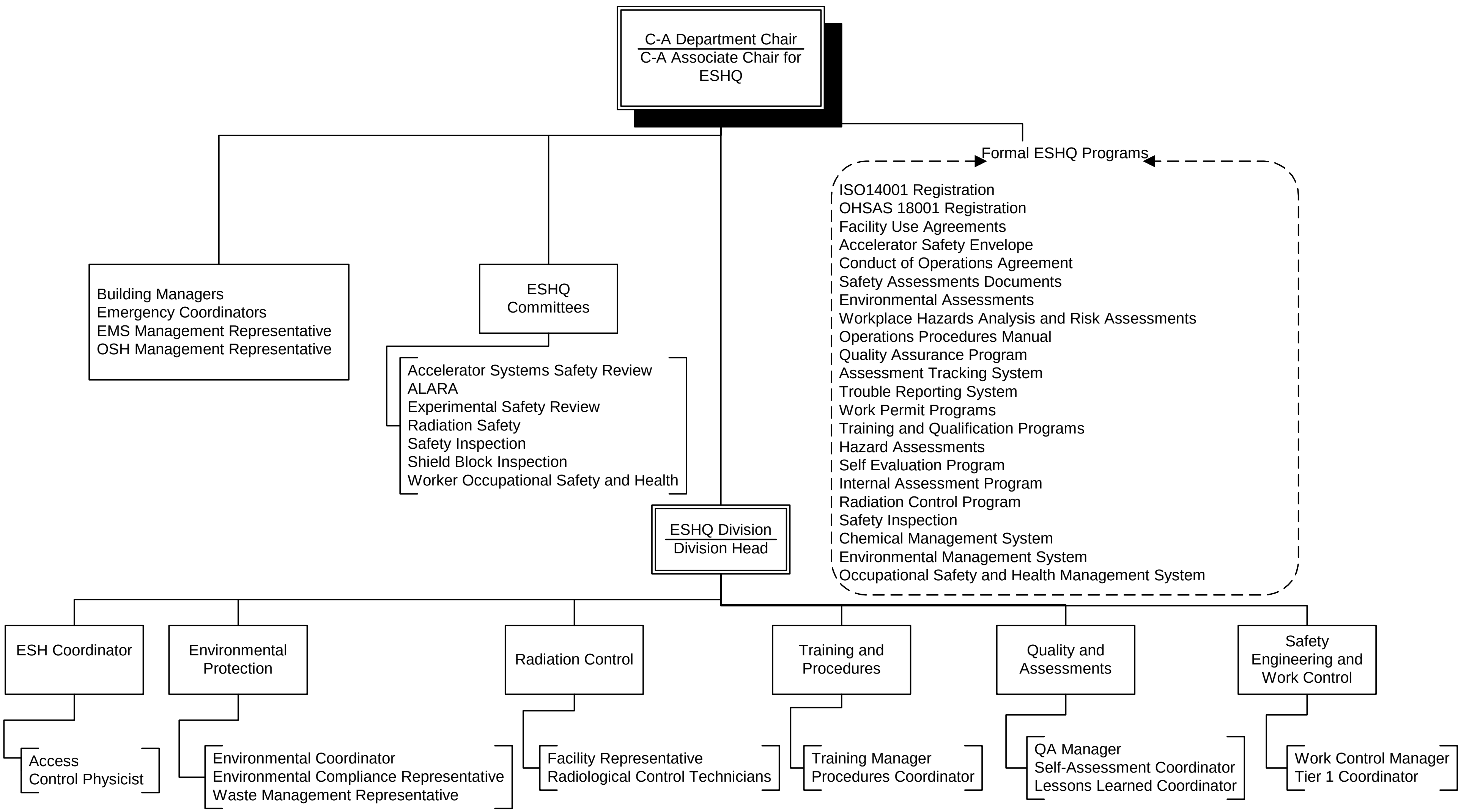
[26] https://sbms.bnl.gov/private/fua/fa00t011.htm Facility Use Agreements
[27] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Department Procedures
[28] http://www.rhichome.bnl.gov/AGS/Accel/SND/procedures.htm C-A Quality Assurance Procedures

The Associate Chair for ESHQ is a member of the C-A Department Chair's Office. The Associate Chair's functions are to implement new or revised environmental, waste, safety, health, training and quality programs, to carry out the leadership role for ESHQ, to inform personnel on the status of ESHQ, to establish communications and to maintain existing ESHQ programs. The overall approach is to integrate ESHQ into all work via formal Collider-Accelerator programs and procedures designed to ensure BNL's management systems are executed. BNL's management systems, which are located in the Standards Based Management System,[29] are in turn designed to ensure that contractual requirements set by DOE are met.

[29] https://sbms.bnl.gov/ch00d011.htm, BNL's Standards Based Management System

Figure 3.5.3 Organization and Formal Programs for ESHQ at C-A Department



For DOE, "safety" encompasses environmental protection, safety and health, including pollution prevention and waste minimization. DOE has identified five Core Functions to manage "safety." They are:

- define the scope of work
- identify and analyze hazards
- develop and implement hazard controls
- perform work within authorization agreement
- feedback and improvement

DOE has identified seven Guiding Principles for performing the five Core Functions. The first three Principles apply to all Core Functions, the others to specific Functions given in parentheses:

- line managers are clearly responsible for "safety" (all Core Functions)
- clear "safety" roles and responsibilities are defined (all Core Functions)
- competence is commensurate with responsibilities (all Core Functions)
- priorities are balanced (define work)
- "safety" standards and requirements are identified (define work, identify hazards, develop controls)
- hazard controls are tailored to work (develop controls)
- operations authorization has been given (perform work)

The management system that includes the five Core Functions and seven Guiding Principles has been named the Integrated Safety Management (ISM) by DOE. BNL's management systems to implement ISM are located in the Standards Based Management System (SBMS). SBMS is on-line with links to all referenced documents. The SBMS satisfies the contractual requirement for ISM. SBMS includes the following principal ESH programs and management systems:

- BNL's Integrated Assessment Program
- Laboratory level work-definition documents such as Subject Areas and BNL ESH Standards
- Facility Use Agreements (FUAs)
- Role, Responsibility, Authority and Accountability documents (R2A2s) and performance goals
- Brookhaven Training Management System (BTMS)

At the Department level, SBMS guides planning and control of experiments, and it is used to:

- determine the concept and scope of the experiment; assess for special requirements, review hazards and safety concerns
- develop an experimental plan and identify controls
- set up an experiment and obtain Experimental Safety Review Committee concurrence
- approve start-up and perform the experiment according to plan
- determine ways to improve next time

In order to guide operations and maintenance of the accelerators, beam lines and associated systems at the Department level, SBMS guides work planning and control for operations, and it is used to:

- define the scope of work in a Work Permit or establish the applicability
- identify the hazards via the Work Permit process and perform a pre-job walk down
- use the Work Permit processes to establish hazard controls and required training
- provide the pre-job briefing and perform the work according to plan/permit

- use the Work Permit feedback process to identify ways to improve next time

The C-A Department uses safety committees and ESH staff to define the scope of the experiment or work, identify and analyze hazards and develop hazard controls. The ALARA Committee, Experimental Safety Review Committee, Accelerator System Safety Review Committee and Radiation Safety Committee meet requirements established in SBMS. These Committees are composed of members of the C-A Department, other BNL scientific Departments and members of the BNL ESHQ Directorate. These Committees operate under a system of formal procedures contained in the C-A Department OPM.

Self-assessment and self-evaluation are carried out by managers using the Management Review process, by individual Department employees and by C-A Department's Safety Inspection Committee, Shield Block Inspection Committee, Worker Occupational Safety and Health Committee (WOSH) and the Quality Group. Formal procedures for conducting self-assessments and self-evaluations are listed in the C-A Department OPM. Formal tracking is via the Assessment Tracking System (ATS).[30]

Management Review is a process whereby senior managers review C-AD targets and objectives to ensure they relate to critical outcomes and objectives in the BNL contract. They also examine the formal C-AD programs that affect occupational safety and health, environmental protection and self-assessment. They review compliance audit results, performance versus contract measures, other external and internal assessments of performance, decisions from previous Management Reviews, injury/illness and environmental performance, stakeholder concerns, related facility improvements, injury/illness and pollution prevention initiatives, and related financial investments. At the end of the process, senior management

[30] http://ats.bnl.gov/ Assessment Tracking System

provides a record of decisions to drive the next cycle of continuous improvement in occupational safety and health and environmental protection.

The WOSH Committee ensures arrangements and procedures are established and maintained for receiving, documenting and responding appropriately to worker communications related to OSH. They ensure that the concerns, ideas and inputs of workers and their representatives on OSH matters are received, considered and acted upon. Each calendar quarter, the WOSH Committee reviews results of injury/illness investigations, performance indicator data, feedback from the Work Planning System, feedback from the Self Evaluation Program, Critiques and Occurrences and they are asked make appropriate recommendations from the workers' perspective.

3.5.4. Third-Party Certification Programs for Management of ESH

The C-A Department employs third-party certification for its Occupational Safety and Health (OSH) management system (MS) and its environmental management system (EMS). OHSAS 18001 (OSH MS) and ISO 14001 (EMS) are the standards used for third-party certification. The certification process and associated registration are discussed briefly below. Certification is the process by which a third party confirms, in writing, that an organization's management system meets the specified OHSAS 18001 or ISO 14001 requirements. Certification means C-A Department's management systems meet all requirements of the standards. The certification process involves an established framework of assessments. The certification body is the third party that actually assesses the organization's management systems. This certification body is often referred to as a "registrar" or certification company. Registration is the process by which the certification body, having verified that an organization's management system conforms to the standard, either OHSAS 18001 or ISO 14001, then includes or "registers" the management system in a publicly available list.

The certification process in general functions in the following manner. C-A Department or BNL selects a registrar to assess its management system. The certification body employs auditors to conduct the assessment. If the auditors determine that the OHS MS conforms to OHSAS 18001 or the EMS conforms to ISO 14001, then the certification body issues a certificate of registration that details the scope of the OSH MS or EMS. The information is made available to the public through a listing in a register or directory, and the C-A Department is entitled to display proof of certification. Certificates of registration are typically valid for three years, although this can vary depending on individual certification body requirements. Certification bodies typically conduct surveillance audits, essentially less-detailed assessments, on a six-month or annual schedule. When the certificate of registration expires, the certification body will typically conduct a complete reassessment, or conduct an assessment that is more comprehensive than the periodic surveillance audits.

The initial certification assessment consists of the following seven steps:

1. Identification of Scope and Management System Implementation: The C-A Department identified the site and scope of the certification effort. The Department conducted an initial review of its practices, processes and procedures to evaluate initial level of conformance with respect to OHSAS 18001 and ISO 14001. The Department then proceeded to implement the requirements of the standard. When the Department felt that it has successfully implemented management systems that met

the OHSAS 18001 and ISO 14001 requirements, it began the certification process by submitting an application to the certification body.

2. Application Submittal: The application submitted by the Department to the certification body identified the rights and obligations of both the certification body and the Department. The application addressed confidentiality issues, the right to appeal and dispute assessment findings, and instructions for use of the certificate of registration.
3. Document Review: Existing documentation relating to the Department's OSH MS and EMS was gathered and reviewed by the certification body in advance of the actual on-site assessments.
4. Pre-Assessment or Pre-audit: The pre-assessment was an on-site assessment that allowed the certification body to gain an initial understanding of the operations at the C-A Department and to have an initial look at the functioning of the management systems. The two main purposes of the pre-assessment, sometimes called a readiness review) were to prepare the involved parties for the ensuing process by providing a broad overview of operations and the audit process, and to determine the overall readiness of the management systems for a comprehensive assessment.
5. Assessment or Audit: Once it was determined that the existing management systems were at an adequate level to be audited, an assessment team visited the C-A Department. The assessment team was comprised of a lead auditor and several support auditors. The length of the on-site audit was about five days. During the assessment, the auditors verified that the C-A Department's management systems conformed to the OHSAS 18001 and ISO 14001 requirements through interviews

with key personnel, site inspections and review of management system documentation.

6. Certification: Three results were possible from this process: a) approval whereby the C-A Department's management systems demonstrated acceptable conformance with the requirements of the OHSAS 18001 and ISO 14001 standards, b) conditional or provisional approval whereby the C-A Department's management systems had minor non-conformances that can be easily rectified and reassessed within a specified period, and c) disapproval whereby the management systems did not demonstrate conformance with OHSAS 18001 and /or ISO 14001. Disapproval is typically issued in cases where basic elements of the standard, such as auditing or corrective action, have not been addressed at all. If C-A Department's management system is ever disapproved, the Department must correct the deficiencies prior to the certification body conducting a reassessment.
7. Surveillance: To ensure that the Department's OSH MS and EMS continues to be in conformance after the initial assessment, the certification body will conduct periodic surveillance audits. Surveillance audits are typically conducted on a semiannual or annual basis, depending on the specific requirements of the certification body.

3.5.5.Calibration and Testing Summary for Engineered Safety Systems in Use

A standard set of calibration and testing requirements is used throughout the C-A Department complex to ensure the operational integrity of the Accelerator Safety Envelope. These requirements are set by authorities having jurisdiction, such as BNL's Fire Protection

Engineer or BNL's Radiological Control Manager. The requirements for calibration, testing, maintenance, accuracy or inspections for engineered safety systems in use are as follows:

- the access control system is functionally tested in accord with requirements in the BNL Radiological Control Manual and testing does not exceed 12 months
- the beam instrumentation system is functionally tested in accord with requirements in the C-A OPM and devices are tested at beam startup and periodically throughout the running period thereafter
- building ventilation exhaust fans associated with ODH protection systems undergo annual functional testing, flow-rate measurements and maintenance and does not exceed 15 months
- fire protection/detection undergoes annual testing in accord with NFPA 72 and does not exceed 18 months
- area radiation monitors undergo annual testing that does not exceed 15 months
- radiological barriers undergo annual visual inspection and inspections do not exceed 15 months
- rainwater barriers for activated soil undergo annual visual inspection and inspections do not exceed 15 months

3.5.6. Administrative Controls for Routine Operation and Emergency Conditions

The administrative controls for routine operation and emergency conditions are:

Fire Hazards - Combustible material usage is kept to a minimum level, as dictated by the instrument and equipment needs. Substitution of non-combustible materials is done wherever feasible. Flammable materials cabinets are provided as required. The Experimental Safety

Review Committee reviews all combustible experimental materials. Fire hazards for the facility are addressed in detail in Fire Hazard Analysis documents.

Magnetic Fields - Magnets are used in the beam line. Any significant magnetic fields produced by these magnets are contained within beam line enclosures or limited access areas. Areas where the magnetic fields are greater than 0.5 mT (5 Gauss) are posted with warning signs for personnel with pacemakers or other medical implants. Medical evaluation and training of personnel with such devices is required before entry into the areas. Additional postings are used for fields greater than 600 Gauss, as per requirements in BNL's SBMS. Training and evaluation of work practices is required for all personnel expected to be exposed to magnetic field strength greater than 60 mT (600 Gauss). Training deals with the possibility of injury due to magnetic forces on objects.

Electrical Safeguards - Electrical safety implementation for design of equipment is covered by C-A Department OPM. Lockout/Tagout (LOTO) procedures are followed for areas where electrical hazards are present. Workers who perform work on electrical systems have LOTO training as specified by BNL. If it is necessary to work on any equipment while it is energized, a Working Hot Permit is issued.

Protective Clothing - Any use of chemicals, hazardous materials or cryogens requires review for personnel protective equipment. The clothing for a particular application is selected considering the expected hazards; a variety of clothing is likely to be needed to meet all hazards. Heat stress and flammability of protective clothing is considered in specifying protective clothing requirements.

Material Handling - All material handling is conducted in accordance with procedures in the C-A Department OPM and requirements in SBMS. Positioning of equipment may require the use of forklifts, overhead cranes and specialized lifting equipment. All personnel operating such equipment are appropriately trained. All material handling equipment is inspected by appropriate BNL personnel.

Elevated Work - Any work required at levels more than four feet above ground level undergoes Work Planning and fall protection evaluation.

Emergency Procedures - Emergency response is governed by procedures in Chapter 3 of the C-A Department OPM. The emergency plan covers possible hazards, emergency signals and expected responses. Each building at the C-A Department complex has signs posted indicating the emergency assembly areas, and the name and number of the Local Emergency Coordinator (LEC). The LEC is familiar with the hazards in the building, the utility locations and shut-offs, and any spill response supplies available. The LEC assists the Fire Rescue Group Incident Commander in responding to any incidents at the facility. Certain C-A facilities have separate emergency procedures in Chapter 3 of the OPM in order to document important, area-specific emergency information.

Radiation Protection – The radiation protection program at C-A Department is in accord with the BNL Radiological Control Manual[31], which in turn complies with Title 10 Code of Federal Regulations Part 835, Occupational Radiation Protection. The C-A Department OPM includes task-specific and RSC- and ALARA Committee-specific radiological procedures, which are used to implement the BNL radiological control system at high-energy particle accelerators.

Beryllium Exposure – Some beam-line vacuum pipes are made of beryllium, including bolts. Some of the water-cooled bases for fixed platinum targets are made of beryllium. These items are purchased and not machined on-site. Beryllium bolts are nickel coated to reduce the potential for airborne releases when bolts are loosened or tightened on beryllium vacuum pipes.

[31] https://sbms.bnl.gov/program/pd01/pd01t011.htm BNL Radiological Control Manual.

The exposure hazard is associated with handling beryllium items and the potential for creating airborne beryllium during this handling. SBMS requirements for beryllium are followed and the BNL Beryllium Use Review Form or its equivalent is used when beryllium handling is anticipated.

Asbestos Exposure – Asbestos is present in many buildings at C-AD, primarily in pipe insulation, ceiling tiles, gaskets, thermal insulation, cement boards and pipes, flooring material, and in roofing products. The location of asbestos areas is known. It may also be found in equipment such as in some older electrical wiring insulation. C-AD does not conduct operations that disturbs or removes asbestos. If asbestos-related work is anticipated, then C-AD contacts asbestos removal experts in Plant Engineering who use written exposure control procedures based on the SBMS Subject Area for Asbestos.

Lead Exposure – Lead (Pb) is encountered in the form of shielding in the beam areas. Handling Pb may be hazardous and C-AD requires the use of use protective equipment such as gloves. Pb may be found in brick, sheet or cast forms, or as wool that is used in Pb blankets. In most applications, the bare metal is covered or painted if practicable. Safety shoes are also required in addition to gloves when handling Pb bricks or sheets of Pb. C-AD staff do not shape, drill, or otherwise work with Pb in any way that causes it to become dispersible.

Shift Manning Requirements – The minimum number of shift operating personnel at C-A facilities during normal and emergency operations is specified in the C-A OPM. These minimums are also stated in the ASE.

3.5.7.Critical Operations Procedures

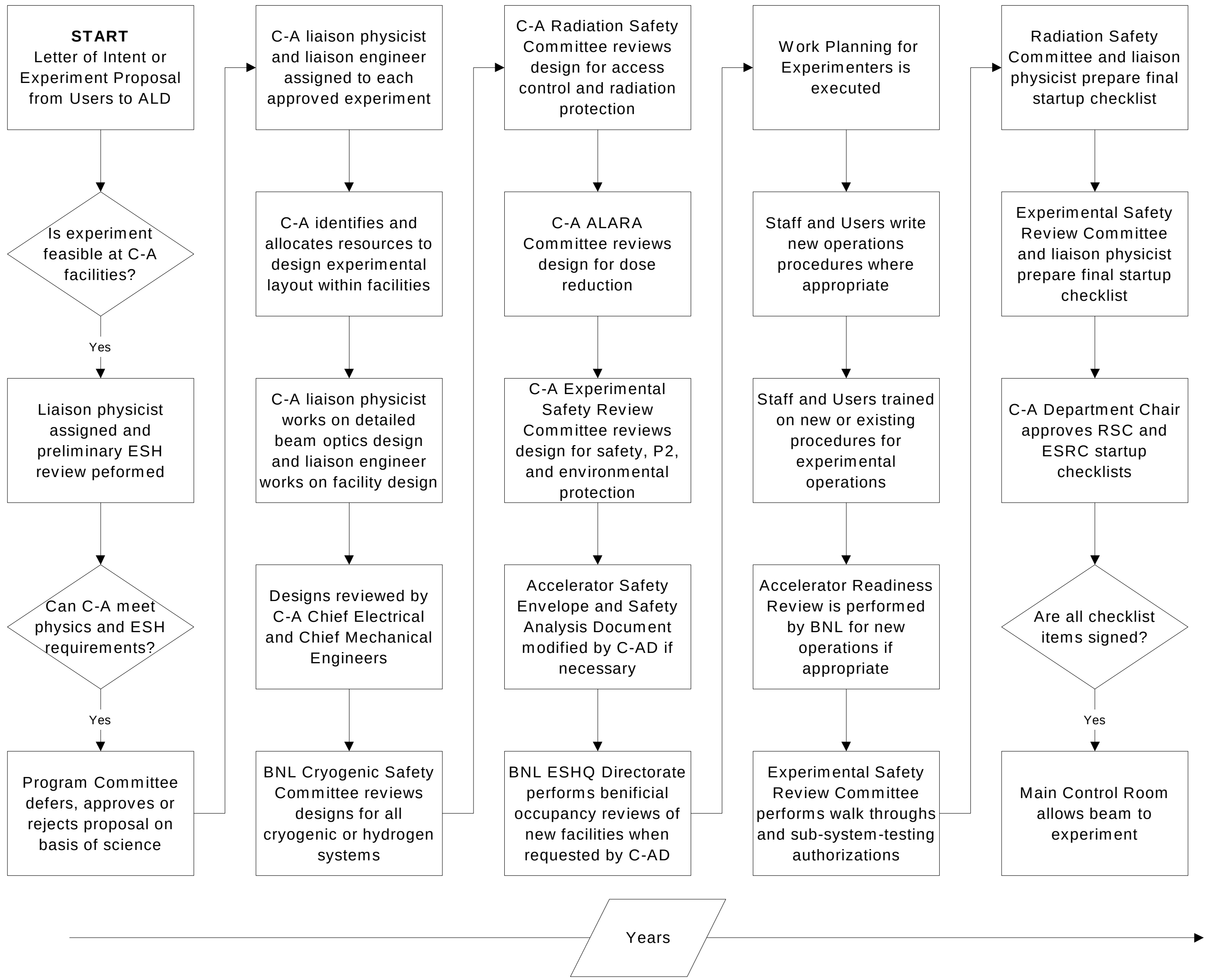
Specific operations procedures that prevent or mitigate accidents are related to resetting the Access Control System in order to enable beam from the MCR. These specific critical procedures involve clearing (sweeping) personnel from beam lines before enabling the beam line for potential operations. These procedures are found in Chapter 4 of the C-A Department OPM. The basic principles behind the authorization and use of these procedures are:

- wording must be consistent throughout the entire set of sweep procedures for the C-A Department; that is, specific terms must mean the same regardless of the location of the area being cleared of personnel
- before resetting for beam, it must be clear to the operator which sweep procedure from the set of sweep procedures applies under every access condition encountered in the field. If not, then the area is not reset for beam
- checklists are checked-off by the operations staff performing the sweep at the completion of each sequential step in the procedure
- annual re-training of operations personnel in access control procedures is performed
- new or modified sweep procedures must receive an independent review by the maintenance staff or their representative; these are staff normally cleared (swept) from the area
- if the Operations Coordinator assigns a gate watch to record access and egress, then the gate watch task is solely to count personnel into and out of the interlocked area; no other duties may be assigned to the gate watch such as checking training records or checking personnel dosimeters

3.6. Experiment Design Criteria

Liaison Physicists, Liaison Engineers, Experiment Spokespersons and members of the Collider-Accelerator Experimental Safety Review Committee (ESRC) have primary responsibility for reviewing an experiment to ensure it meets design criteria. Experiment review within the C-A Department has many steps. A flow diagram of the experiment review process is shown in Figure 3.6 and it applies to the experimental program as a whole. If there are no significant modifications or program changes to the experimental area during any given year, then the last 10 steps shown in Figure 3.6 are repeated before each running period. If proposed modifications or program changes to the experimental area exceed the limitations of the ASE, then the whole process represented in Figure 3.6 is repeated.

Figure 3.6 C-A Department Experiment Review Process



The C-A Department OPM experiment design criteria comply with SBMS requirements for planning and control of experiments. However, the term Liaison Physicist as used within the Department is equivalent to the term Experiment Review Coordinator as used in SBMS. The term Experiment Spokesperson is equivalent to the term Lead Experimenter as used in SBMS.

At C-A Department, an experiment or experimental area may lie dormant for a period greater than one year between runs and not require a review during the dormancy period. The Department reviews each scheduled experiment or experimental area before a running period. The running period may be continuous for many months and overlap a fiscal year or a calendar year. A second annual review would not be required if the experiment is in continuous operation for longer than 12 months and there are no significant changes to the experiment area. A running period significantly longer than 12 months is rare. If more than one running period occurs within a 12-month period, then review by the ESRC must occur for each scheduled experiment even if it results in a review of any specific experiment twice in one year.

The ESRC assures that the experiment's design does not exceed the approved ASE, or the scope and impacts described in any pertinent NEPA document such as the Environmental Assessment. For "critical" safety items, defined as items that must be closed out before start of operations of the experiment, the Liaison Physicist is responsible for ensuring closeout. The C-A Department Chair approves all experiment installation and the start of experimental operations before each running period.

Before the ESRC review, the Liaison Physicist, Liaison Engineer and/or the Experiment Spokesperson provide written descriptions of ESH issues and protective systems. Based on this written description, special subject-matter experts are called to join the ESRC for advice or review on an ad hoc basis. The experimenters are not allowed to operate or change experimental parameters beyond their approved envelope until satisfactory review by the ESRC. In addition, the Experiment Spokesperson must fulfill or resolve all pre-start ESRC recommendations and close all outstanding items. For changes beyond the approved envelope, the Liaison Physicist or the Experiment Spokesperson is responsible for notifying the ESRC Chair or the C-A Associate Chair for ESHQ, early in the planning phase.

For non-commercial experimental devices, the ESRC may request a certification of the device from the C-A Department's Chief Electrical Engineer or Chief Mechanical Engineer. Chief Engineer certification procedures are defined in the OPM.[32, 33]

The ESRC must ensure an environmental evaluation is performed for each experiment in conformance with requirements in SBMS. Any equipment or experimental materials with environmental aspects are examined. For example, the ECR to the C-A Department evaluates the potential consequences of a break in a buried pipeline, a spill onto soil or an accidental release to the air, sanitary sewer or storm drain, and any non-radioactive air emissions, radioactive air emissions, or liquid effluents.

Experimental procedures must comply with Conduct of Operations requirements for emergency procedures, operating procedures, training requirements and experienced staff during running periods. This is accomplished using the Work Planning for Experiments procedure in the OPM.

Pollution prevention is examined by ensuring experimental activities that involve purchasing, using or disposing of hazardous material or radioactive material is reviewed to reduce waste generation whenever possible. The ESRC considers measures to avoid or reduce the generation of hazardous substances, pollutants, wastes and contaminants at the source. The

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[32] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-02-03.PDF Procedure for Chief Engineers to Certify Conformance of Devices

[33] http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch09/09-03-04.PDF Review and Approval of Electrical Equipment In-House

experimenters must have plans to reuse, if practical, hazardous material that cannot be eliminated, and have plans to treat the remaining waste to reduce the volume, toxicity or mobility before storage or disposal. The ESRC ensures that experimenters have identified a disposal path for all anticipated wastes before the experiment.

As a final point, the ESRC ensures that relevant Facility Use Agreements[34] are updated whenever affected by a modification to the experimental areas.

3.7. Characteristics of Experimental Systems Having Safety-Significant Functions

3.7.1. Experimental Systems Having Safety Functions at TVDG Target Rooms

Four separate target rooms exist in the facility. Three remain as active target rooms, and one, Target Room 3, is no longer in use as a target area. Several distinct beam lines are available in each active target room, providing a great deal of flexibility to experimenters. Covered trenches provide access to cable runs and utility services. Each room has a 30-ton steel shielding door for entry and exit from the main corridor. In addition, Target Room 4 also has an escape passage from Accelerator Room 2 located at its north-west corner. The shielding door is approximately 3 feet thick; the walls between adjacent target rooms are approximately 4 feet thick; the walls separating the target rooms from the corridor are approximately 6 feet thick.

The only fixed equipment in the three active target rooms are the beam lines and associated beam transport components. The fixed safety systems in the experimental areas are the access control system and emergency stop buttons. If a target room has not been

[34] https://sbms.bnl.gov/private/fua/fa00t011.htm BNL Facility Use Agreements

swept and secured prior to the onset of a radiation condition, or if a secure entry-point is violated with the target room in a secure condition, then the access control system will immediately insert a beam stop in the accelerator room to remove beam. Two separate beam stops are inserted. The redundant response removes beam from the affected target room. The system generates visible and audible signals on the system status panel indicating a "Radiation without Interlock" condition. A final level of personnel protection is provided for by the presence of emergency stop buttons located throughout the target rooms. These are large, illuminated, red pushbuttons labeled with "EMERGENCY STOP" signs. Should a person have cause, the one can activate the nearest switch.

Experiments in Building 901A are evaluated for potential safety hazards and environmental impacts in accordance with the C-A Department procedures. For experiments that are not initiated by outside users, the Principal Investigator or project manager is responsible for informing the appropriate C-A Department safety committee of projects requiring review and for providing necessary documentation. Outside users of the TVDG are required to complete a checklist that includes safety concerns. The TVDG Operation Supervisor brings any significant safety issues to the attention of the appropriate safety committee. The committees review safety related issues and make recommendations. Currently, other than access controls to the TVDG target rooms themselves, there are no experimental systems having safety functions at TVDG.

3.7.2. Experimental Systems Having Safety Functions at Booster's NSRL

For the majority of users at C-A facilities, biological safety is not an issue; however, it is an issue for programs at NSRL. Long-term experimental procedures with animals or biological materials are carried out in the user's own institution or in the BNL Medical Department or Biology Department; the C-A Department provides only short-term holding facilities for biological specimens.

The experimental systems that the users investigate at C-A facilities include:

- cultured non-human mammalian cells
- cultured human cells
- primary human cells such as small samples of blood obtained in medical facilities under Institutional Review Board[35] approval and transported to C-A Department by approved means
- isolated non-hazardous biological molecules, e.g., DNA
- standard laboratory animals such as Drosophilae (fruit flies), Nematodes (worms), chickens, rats and mice

Specific biological materials beyond those described here are reviewed on a case-by-case basis by the BNL IBC.

The potential for handling human blood dictates that a Biosafety Level 2 facility is provided. Biosafety Level 2 practices, equipment and facilities are appropriate when any work is

[35] BNL Institutional Review Board (IRB) https://sbms.bnl.gov/ld/ld16/ld16d051.htm

done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown.[36]

For Biosafety Level 2, facility design specifies that the cell rooms are separated from general public access areas and hand-washing facilities are provided. To minimize external contamination of critical samples by increasing ease of facility cleaning and maintenance, scrub-able walls and poured-resinous seamless floors with closeable drains are specified.

All materials, including Regulated Medical Wastes, are transported by users back to the long-term facilities in the BNL Medical Department, and these transportation activities are reviewed and approved during experimental safety review by the ESRC. Transportation activities between C-A Department facilities and the Biology and Medical Departments are in accord with SBMS.

Safety equipment includes Class II biological safety cabinets to provide significant levels of protection to laboratory personnel and to the environment when used with good microbiological techniques as well as protect the experimental samples from external contamination. Personal protective equipment (PPE) such as laboratory coats, gloves and safety glasses are available. The Biological Safety Cabinet is appropriate for Biosafety Levels 2 and 3, but is not designed for volatile chemicals, as it re-circulates the air through a HEPA filter into the laboratory. Persons using blood or other tissues with the possible hazard of Blood Borne Pathogens receive appropriate training. All experiments using human cells and tissues are reviewed by the BNL IRB as well as the IRB of the Users' institutions, as appropriate.

Laboratory-animals are kept at C-A Department for less than 24 hours and for USDA regulated species, they are kept less than 12 hours. Exceptions to this 24 hour/12 hour rule may

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[36] Biosafety in Microbiological and Biomedical Laboratories (BMBL) 4th Edition, HHS, CDC, U.S. Government Printing Office, April, 1999 http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4toc.htm

be approved by the Institutional Animal Care and Use Committee (IACUC) on a case by case basis.[37] The animal facility is designed and constructed to facilitate cleaning and housekeeping. This includes poured-resinous, seamless floors and washable walls. The facility has its own entrance, and the wing of the building containing the animal facility is closed from the general corridor by double doors. The facility has its own air handling system, which is vented away from the intakes of the other air handling systems. No studies of infectious agents are anticipated at C-A Department. Animals and cages are returned to the BNL Medical Department. Hot water hoses are used for washing animal racks at the animal facility.

There is no need to prohibit animals from the facility in case of ventilation problems due to the limited amount of time animals will be housed there. The facility has locks on the doors and a card reader at the entry. All personnel entering the animal facility have previously been issued keys or key cards, and placed on a facility access list.

Current users have not proposed the use of recombinant DNA materials at BNL. In the context of the National Institutes of Health (NIH) Guidelines, recombinant DNA molecules are molecules that are constructed outside living cells by joining natural or synthetic DNA segments to DNA molecules that can then replicate in a living cell. Although improbable, some recombinant DNA may cause serious or lethal human disease. If use of recombinant DNA materials prepared at a user's home institution is proposed, then the user must submit a copy of the home institution's Institutional Biosafety Committee (IBC)[38] approval. Additionally, a copy of the risk assessment analysis, a transportation plan in accord with DOE and International Air Transportation Association rules, and a description of the material must be forwarded to the BNL IBC for their consideration and approval before approval to bring such material to the NSRL is

[37] Unreviewed Safety Issue, http://www.rhichome.bnl.gov/AGS/Accel/SND/USI/NSRLUSI.pdf
[38] Institutional Biosafety Committee HTUhttps://sbms.bnl.gov/ld/ld16/ld16d341.htmUT

given. It is unlikely that recombinant material will be constructed at BNL; however, any such experiments would be reviewed by the BNL IBC and NIH Guidelines shall be followed.[39]

Transportation of experimental samples/equipment, etc. to or from BNL is by DOT rules; experimental investigators are informed of this requirement when they register via the BNL Guest Information System. On site transportation of user's equipment, radioactive materials, regulated medical waste and biohazards, is performed after appropriate packing, labeling and documentation of the material, according to BNL requirements in SBMS.

3.7.3. Experimental Systems Having Safety Functions at AGS Fixed Targets

The potential hazards associated with fixed target experiments include radiation, high voltage, high current, cryogenic conditions, mechanical hazards due to massive components, flammable gasses, lasers and high vacuum. Radiation safety requirements for specific experiments are established and posted for each experimental area, and users are trained on how to use the Access Control System associated with their experiment. In addition to the hazards of contact with energized electrical circuits, the short-circuit capacity of the 120/208 and 480-volt systems is much above that encountered at most industrial and/or research facilities. Therefore, connection and disconnection to a C-A power distribution system is made only by qualified BNL personnel. Central power shutdown switches are designed for each experiment should they be needed in the event of a local fire or similar emergency. Experiments requiring radiation or ODH interlock functions have these safety systems as an integral part of the Department-wide ACS that was previously described.

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[39] NIH Guidelines for Research Involving Recombinant DNA Molecules
http://www4.od.nih.gov/oba/rac/guidelines/GUIDELINjan01rev.pdf

The use of liquid hydrogen occurs occasionally in high-energy fixed target experiments. When an experiment involves the use of liquid hydrogen, all work associated with this flammable cryogenic fluid is performed by qualified BNL personnel. The experiments may use several liters of liquid hydrogen as a fixed target. Cryogenic target enclosures are sufficient to contain and vent the hydrogen should target containment fail. Automatic fail-safe venting is designed to occur should a fire break out near the target, should a power failure occur or should a leak develop at the target or target vacuum. Safety review of the design and a design analysis for hazards are performed for each target. A cryogenic target watch is assigned round-the-clock during operations with liquid hydrogen targets.

The targets are located in secondary beam lines typically upstream of spectrometer magnets. The support stands for the targets generally allow them to move several feet out of the beam. Target controls, monitoring and hydrogen detection is located downstream typically at the downstream side of the dump shield for the secondary beam line. Dump shields for these beams are typically eight-foot high, four-foot thick concrete blocks.

The target vessels have upstream and downstream windows that are typically 6 inches in diameter and constructed of 0.006-inch thick aluminum epoxy laminated with typically 0.01-inch thick Kevlar mesh. Targets are surrounded by Herculite and aluminum sheet metal enclosures with 6-mil Mylar windows for the experimental beam. The enclosure allows air to be drawn past the target equipment and vented into the low-pressure target vent system. The enclosure is designed to contain the hydrogen or deuterium in the event of a total failure of the target system. The electrical equipment inside enclosures meets Class I Division II standards for electrical circuits in explosive atmospheres.

There is no full-time occupancy within an established over-pressure zone near a hydrogen target and equipment racks and monitoring stations are typically more than 30 feet away. These zones are considered low-occupancy areas. Experimenters and watch personnel may walk by or briefly work in the zone; typically, one or two people at a time. In the event of an accidental explosion, peak over-pressures are likely to be significant to move large magnets nearby, collapse the target enclosure and collapse nearby experimental detectors. The nearby secondary beam dumps will likely remain standing.

Safety features include testing target windows against puncture, interlocking the target vacuum sensor and hydrogen detectors to the power supply to nearby experimental detectors, and protecting upstream and downstream experimental detectors and chambers with fire wire and smoke detectors. The fire wire and smoke detectors will interlock the electric power to the experiment and cause alarms to go off alerting both MCR operators and the target watch.

Before a target installation, the environment around the target is reviewed for potential ignition sources. Pre-amps, cabling, power-supplies, gas flow systems, detectors and detector chambers are typically examined. Safety requirements call for written procedures to operate experimental chambers and gas systems around the target. They also call for routine portable sampling for hydrogen or any other flammable gas in use near the target before startup and following shutdown. Voltages on experimental equipment are normally required to be present before hydrogen or deuterium is introduced to the target. Alarm responses are written into formal procedures and the target watch is trained, again before the introduction of hydrogen or deuterium to a target.

Work on or around the target is forbidden unless the hydrogen or deuterium is removed. Fire wire and smoke detectors are required to be operational at all times. Failed smoke detectors are not allowed to be bypassed while the target is in operation.

All lasers in the experimental areas are reviewed by the BNL Laser ESH Officer before initial use or following modification to a previously reviewed laser. Users meet specific requirements, including medical surveillance requirements, established for the laser. Interlocks are from either the laser manufacturer or part of the ACS.

Potential energy hazards are those associated with compressed gases and vacuum windows, as well as those associated with hoisting and rigging operations. These hazards are mitigated by safety reviews and compliance with SBMS and all applicable codes. For large vacuum windows, mechanical methods for controlling access to the window are employed since hearing damage or other injury may occur upon window failure. A metal shutter is used to protect the window during work near the window, and certain shutters are set up to be inserted before entry into the experimental beam line, and extracted when the beam line is in operation.

3.7.3.1.Experimental Area Group Alarm (EAGAL) System

The EAGAL system is designed to transmit alarms from the Target Desk to Main Control and the Collider-Accelerator Systems (CAS) watch. Originally, the Target Desk in Building 912 was continuously manned when the AGS was operating. To more efficiently use the CAS watch the Target Desk alarms were automated to the Main Control Room. This enabled Main Control Room operators to take corrective action themselves or to use the radio to contact the CAS watch. The original automated alarm system was custom-built electronics that had become obsolete and very difficult to repair. Recently, it has been replaced with an Allen-Bradley PLC system.

The Target Desk alarms cover a wide range of possible inputs and outputs. The system has evolved to be adaptable to the varying needs of the experimental areas. Experimental equipment alarms that are routed through the Target Desk and then EAGAL to Main Control include:

- flammable gas detection, bypasses and resets
- emergency generator alarms and resets
- magnet cluster-lockouts
- hydrogen target alarms
- building fan controls
- building evacuate
- crane power controls
- magnet cooling water status
- beam line vacuum alarms
- shield top access key status
- miscellaneous alarms that are requested by the experimenters

Although specific equipment is discussed in the following, alarm system components may vary in the future as technology warrants. Target Desk alarms are input to an Allen-Bradley SLC-5/04, which is located in Building 940, through remote input-output blocks that are located on the first floor of the Target Desk. The alarms are sent via a remote input-output link to a PLC-5/V40B that is located on the second floor of the Main Control Room in Building 911. The PLC-5/V40B is an Allen-Bradley PLC, which resides in a VME chassis. This is the connection to C-A Controls for recording of alarms and displaying of alarms in the Main Control Room. As a back up, the alarms are also sent by separate line to Panel View display screens in Main Control and Building 940, where the CAS watch resides. There is a continuous “heart beat” signal between the SLC-5/04 and the C-A Controls. If this link is lost, then an alarm will display on the C-A Controls screen and the Panel View screens.

Currently, and at most times, the majority of the possible 768 alarms through EAGAL are masked off. This is due to the ability to handle flammable gas and hydrogen targets at many locations in Building 912, which were not in use at the time of this writing. When an alarm is masked, the status is not displayed on the EAGAL system. This is done to avoid nuisance alarms from sensors that may drift during a long period when they are not in use.

3.7.4.Experimental Systems Having Safety Functions at RHIC Intersecting Regions

The potential hazards associated with experiments at the RHIC IRs include radiation, high voltage, high current, mechanical hazards due to massive components, flammable gasses, lasers and high vacuum. As is the case with fixed target experiments, radiation safety requirements for specific experiments are established and posted for each experimental area, and users are trained on how to use the Access Control System associated with their experiment. In addition, connection and disconnection to a C-A power distribution system is made only by qualified BNL personnel. Central power shutdown switches are designed for each experiment should they be needed in the event of a local fire or similar emergency. Experiments requiring radiation interlock functions have these safety systems as an integral part of the Department-wide ACS that was previously described.

While some experimental hazards can be categorized as routinely accepted, others are classified as experiment specific hazards that require safety systems. In particular, PHENIX and STAR experiments have systems with safety functions specific to their experiments for equipment protection. Alarms from systems with safety functions at RHIC experiments go through systems similar to EAGAL in that they are interfaced to C-A Controls through PLC-5/V40 interfaces at each IR.

PHENIX is a complex system with potential hazards typical of large detector systems. PHENIX has adopted the approach of providing a Safety Monitor and Control System (SMCS) that continuously polices the PHENIX sub-systems and local environment inside the PHENIX Experimental Hall. The PHENIX SMCS is an active, real time, monitoring and control system that takes inputs from gas, smoke and fire detection systems as well as the emergency crash button circuit. It can also accept a crash signal from any one of the PHENIX sub-systems.

Upon detection of an off-normal situation from any input, or activation of a crash button, the SMCS can respond by tripping a master contactor that will reach back to the power breakers and remove all clean and utility power inside the hall. In parallel with the power shutdown, the SMCS can also initiate the following actions:

- shutdown of detector gas and initiate a safe purge
- signal to PASS and activate emergency exhaust fans and HVAC
- communicate and alarm to the local Fire Control Panel
- communicate and alarm to MCR
- communicate and alarm to PHENIX Control Room

The SMCS receives its electrical power from an independent, non-common branch circuit. The branch circuit is tied into the Emergency Power System, which is a diesel generator, to assure continuous operation during long-term power outages. A UPS protects against dips and short-term interruption.

Much of the electronics in PHENIX is housed in enclosed racks mounted on the carriages and magnets. These racks contain high voltage for the detectors, low voltage power for the on-detector electronics, as well as some detector electronics. These racks have an internal interlock system capable of sensing temperature, smoke, coolant loss and local manual crash. They can also be powered off by remote control.

Detector gas systems, either recirculating or single-pass, during normal operation continually take make-up gas while venting an equal amount outside the IR through the Low Capacity Vent Stack. Exhaust pipes vent to this 30" diameter shaft in the South West corner of the IR about twenty feet up the West wall. A special fan arrangement ensures a constant and steady backpressure for all systems and dilutes the mixture of all flammable gases to less than 25% of the Lower Explosive Limit. This fan runs continually during operations with gas and is interlocked. A second and similar stack in the North West corner is used for off-normal modes of operation such as detector purges, overpressure venting, and emergency pump-downs. The stack ducting and fan exhaust is strategically oriented to vent stack gases away from potential sources of ignition and building air-handler intakes. The vent stacks satisfy the criteria for venting of flammable gases.

The STAR experiment has a series of interlocks both in the overall STAR integration program and in each experimental subsystem. Typically, interlocks include smoke and heat detection, gas detection, and water leak detection. Depending on the detector activated, the interlock system has the capability of isolating electrical power to an experiment rack or isolation of the entire experimental and magnet electrical system. The interlock system can also initiate a purge of the flammable gas system.